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PRUNING AND FERTILIZATION EXPERIMENTS WITH CONCORD GRAPES

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The grape is one of the important fruit plants grown in the Niagara District of Ontario, and Concord is by far the most important variety. Growers have been seeking advice about practices which might increase the yield and quality of their Concord grapes and up to the present there has been very little data on which to base answers to their questions. Realizing the dearth of information on this subject the Horticultural Experiment Station commenced pruning and fertilization experiments in the spring of 1929 at the Haines vineyard about two miles east of Jordan. At that time the vines in the experimental plots were 5 years of age and in a very good state of vigour.

REVIEW OF LITERATURE

There is a large volume of literature on pruning and fertilizing the Vinifera type of grape but much less on the Labrusca type. As it is very unlikely that results obtained on the former type can be safely applied to the latter only the literature on the Concord variety (Labrusca) will be considered in this paper. Schrader (9, 10), Partridge (6, 7), and Colby and Tucker (1) have considered the physiology of growth and reproduction in this variety. All have emphasized the importance of maintaining a proper balance between growth and fruit production which means a degree of severity of pruning in keeping with the vigour of the vine. Partridge (7) gives a table of the number of buds to leave on each vine at pruning time based on the weight of prunings removed from that vine. Colby and Tucker (1) suggest the use of the presence of lateral (secondary) shoots as an index of the proper degree of pruning, the desired result being the development of some laterals but not enough to make up one-third of the total growth in length of any vine. There is very little information on the effect of pruning of varying degrees of severity on the sugar and acid content of the fruit. In 1934 the authors published a brief note (12) on the effect of overpruning unfertilized vines at the Haines vineyard, results indicating that overpruning reduces the quality as well as the quantity of the fruit.

In Michigan Partridge and Veatch (8) obtained beneficial results from applications of readily available nitrogen and somewhat lesser effects

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from superphosphate and muriate of potash. Increases in crop were obtained largely as a result of increased wood growth, making possible the retention of more buds at pruning time. Recently Gladwin (3) has published a summary of 25 years' fertilization of Concord grapes in New York State which shows an increased yield from an NPK fertilizer, most of the increase appearing to come from the nitrogen and potassium and relatively little or none from the phosphorus even though it did increase the growth of green manure crops. It would seem, however, that the increases in yield from fertilizers in this experiment were not as significant as indicated because the check plot was quite decidedly poorer than most of the treated plots at the beginning of the experiment. Holland (5), using only the NP combination, found an increase in yield of Concord grapes mainly on the lighter soil types of Ohio. Gourley (4) reported the results of another experiment conducted on a heavy type of soil in Ohio. This test showed that the greatest crop increase came from annual applications of eight tons of horse manure per acre, an NPK fertilizer seeming to be of some benefit but nitrogen alone, of doubtful value. On the other hand, in Missouri Faurot (2) found that nitrate of soda increased the yield but phosphate and potash had no effect even though phosphate improved the growth of green manure crops. In this experiment, though farmyard manure increased growth, it decreased the weight of fruit which suggests too severe pruning on these plots. The only straw mulch plot made rampant growth but the fruit yield was low even though 80 to 100 buds were left on these vines. Using the yields from the fifth to the ninth year after annual fertilizations were commenced Stene (11) of the Rhode Island Station, in a comparison with an NPK fertilizer, found that omission of potassium very considerably reduced yields, omission of nitrogen caused a slight reduction and omission of phosphorus was without effect.

From samples taken from the test plots in 1912 Gladwin (3) concludes that the sugar content of the grapes was not affected one way or the other through fertilization. In his experiments, however, nitrogen had a beneficial effect on size of bunch and berry.

EXPERIMENTAL

Soil

The soil at the Haines vineyard is classified as Vineland Clay Loam and is described as moderately acid in reaction, medium in organic matter, replaceable potassium and nitrogen content, for the most part low in readily soluble phosphorus and with heavy poorly drained subsoil. Many of the grape plantings in the Niagara District are situated on this or a similar type of soil. Up to the time of planting to grapes in 1924 this area of land had been used mainly for grain crops and had received very little manure or commercial fertilizers. Until 1929 no commercial fertilizers had been used for the grapes and only a very limited quantity of barnyard manure.

Weather

There was no appreciable freezing or frost damage in this vineyard in the 8-year period, 1929-36, not even after the severe winter of 1933–34. The very high summer temperatures of 1936 played a part in reducing the

crop in that year. However, possibly the most important weather factor concerned was the supply of moisture, and Table 1 is given to illustrate the extremes in summer and yearly precipitation:

TABLE 1.—TOTAL PRECIPITATION

—	Whole Year	Summer months (June-Sept. incl.)
1929	31.0	8.4
1930	24.0	7.8
1931	30.0	11.3
1932	38.2	12.7
1933	29.7	9.9
1934	24.5	9.9
1935	24.0	6.5
1936	28.4	9.1
21-year mean	28.8	10.8

Cultural Conditions

The vineyard was cultivated from early spring until about mid-July as often as it was neecssary to keep down weed growth. No green manure crops were sown except on 3 plots which were used for comparison, and the weed growth developing after the last cultivation was often very meagre. The pruning and harvesting were done by the Experiment Station. The only spray applied regularly was a Bordeaux-nicotine spray just after the fruit had set.

Plan of Experiment

In Figure 1 the arrangement of series and plots and the treatments are shown. Every third plot is untreated and is used to measure the increase or decrease due to treatment of the adjacent plots. The "normal" of a treated plot was obtained from the formula, $\frac{2}{3}C^1 + \frac{1}{3}C^2$ where C^1 is the nearer untreated plot and C^2, the more distant. As may be seen later in this report the soil did not change in a uniform manner but presented a patchy condition and to this extent the method of analysis fell short; however, by referring to the first year's figures due allowance can be made for this inadequacy.

Shortly after the shoot buds had burst fertilizers were applied on the surface and disked in immediately. They were applied only as far as the end vine of each plot, leaving a buffer area of 9 feet between plots. This is probably insufficient to protect against the dragging of fertilizer from one plot to another but the amount of fertilizer getting into the next plot would be comparatively small. In any case it seemed to the authors that, because of the reduction in the number of vines per plot by the omission of the end vines, there would be less error through their inclusion. However, as the sample of fruit taken for analysis was sufficiently large without them no bunches were taken from the end vines of each plot.

Fertilizer applications were commenced on A, B and C Series in the spring of 1929 and on D series in 1930. Straw was first applied in the fall of 1930 and seed was first sown on the green manure plots in the summer of 1931. Millet was used for 3 years and buckwheat, for one year. In 1935 and 1936, because of dry conditions, summer crops failed and fall rye was sown.

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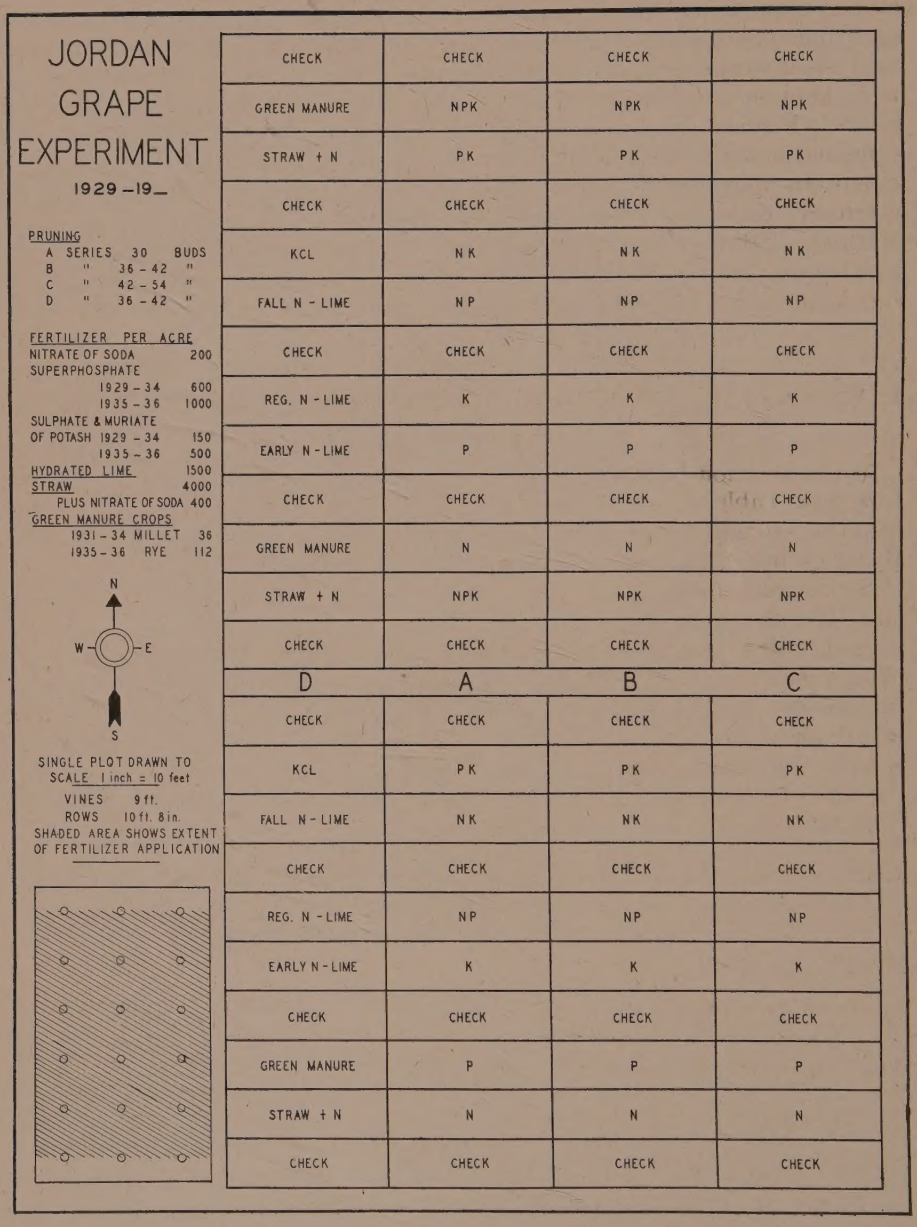
JORDAN
GRAPE
EXPERIMENT
1929 –19_
PRUNING
A SERIES 30 BUDS
B " 36 – 42 "
C " 42 – 54 "
D " 36 – 42 "
FERTILIZER PER ACRE
NITRATE OF SODA 200
SUPERPHOSPHATE
1929 – 34 600
1935 – 36 1000
SULPHATE & MURIATE
OF POTASH 1929 – 34 150
1935 – 36 500
HYDRATED LIME 1500
STRAW 4000
PLUS NITRATE OF SODA 400
GREEN MANURE CROPS
1931 – 34 MILLET 36
1935 – 36 RYE 112
N
W
E
S
SINGLE PLOT DRAWN TO SCALE 1 inch = 10 feet
VINES 9 ft.
ROWS 10 ft. 8 in.
SHADED AREA SHOWS EXTENT OF FERTILIZER APPLICATION
CHECK CHECK CHECK CHECK
GREEN MANURE NPK NPK NPK
STRAW + N PK PK PK
CHECK CHECK CHECK CHECK
KCL NK NK NK
FALL N - LIME NP NP NP
CHECK CHECK CHECK CHECK
REG. N - LIME K K K
EARLY N - LIME P P P
CHECK CHECK CHECK CHECK
GREEN MANURE N N N
STRAW + N NPK NPK NPK
CHECK CHECK CHECK CHECK
D A B C
CHECK CHECK CHECK CHECK
KCL PK PK PK
FALL N - LIME NK NK NK
CHECK CHECK CHECK CHECK
REG. N - LIME NP NP NP
EARLY N - LIME K K K
CHECK CHECK CHECK CHECK
GREEN MANURE P P P
STRAW + N N N N
CHECK CHECK CHECK CHECK

FIGURE 1. Arrangement of series and plots giving treatments of each.

Methods

Individual vine yield records were taken. Where vines were missing, small as a result of later planting, or damaged from Dead Arm disease, the average yield of the other vines of the plot was substituted. As such vines were less than 5% of the total number under experimentation the error was not very great. For weight of prunings the plot was the unit used, the

labour required to obtain individual vine records being too great in such an extensive experiment. Samples of fruit were taken for sugar and acid analysis 2 weeks and again 3 days before cutting the crop. The samples were kept in a cool cellar and analysis was always completed within 60 hours. Berries were picked from the bunches and a uniform volume was squeezed in a Carver laboratory press at 4,000 lbs. pressure. Sugar determinations were made by a method given in Sutton's Volumetric Analysis (10th ed., page 331). This proved to be a rapid and sufficiently accurate method. Total acid was obtained by the Official Method. As only a hand press, which did not give uniform squeezing, was available in 1929 the sugar and acid readings for this year are not included in this paper.

RESULTS

1. Effects of Heavy, Moderate and Light Pruning on Wood Growth, Yield and Quality of Fruit

The relation between wood growth and fruit production is well illustrated in Table 2. A Series has very definitely been overpruned with a resulting strong wood growth made at the expense of the fruit crop. B Series has probably also been overpruned though to a lesser degree. C Series was pruned to 42 buds per vine up until 1934 but in 1934, 1935 and 1936 the number of buds left was 54 which meant an underpruning for some plots though not for others. However, some of the weaker growing plots were showing definite signs of distress in 1935 and 1936. In Plot C10, the poorest in the experiment, vines were beginning to die out. The yield figures show average crops of over 4 tons per acre on B and C Series which is well above the average for the district. It is evident, however, that the vineyard has been failing to a certain extent to withstand the drouth conditions in the summers of 1935 and 1936.

TABLE 2.—EFFECTS OF HEAVY, MODERATE AND LIGHT PRUNING ON WOOD GROWTH, YIELD AND QUALITY OF FRUIT

Series	A	B	C
Number of buds left	30	36–42	42–54
Weight of prunings per acre per year (1932–37) lbs.	1625	1422	1208
Yield per acre per year (1929–36) lbs.	7385	8439	8998
Per cent sugar per year (1930–36)	15.6	15.0	14.9
Per cent total acid per year (1930–36)	.69	.67	.66

Some overpruning results in a slight increase in sugar content of the grape juice but carried to an extreme, as it was on some of the stronger growing plots of A and B Series, sugar content was reduced as has been noted in a previous paper by the authors (12). Considering all the plots in A, B and C Series there has been no appreciable pruning effect on total acids in the grape juice but considering only the extremely vegetative plots, total acids were always higher than the average. Judging from sugar and acid content of the juice there is no reason for deliberate overpruning to improve eating quality particularly when quantity of fruit is thereby reduced.

There is the companion question as to whether underpruning adversely affects quality. Up to 1934 there were no plots in the experiment which were definitely undervegetative as a result of underpruning but the authors supposed (12) that this condition would result in low sugar and high acid content of the juice. Having, from 1934 on, increased the number of buds left on C Series from 42 to 54 per vine some of the poorer plots became definitely undervegetative. To learn that the sugar content of the juice from these plots was slightly higher than the average for all plots and the total acids were somewhat lower was quite surprising. However, the berries were small and the bunches small and loose. A comparison of the 1936 fruit of two unfertilized plots, C7 and C10, not far removed from one another, but showing contrasting growth conditions is illustrated in Figure 2. It is quite apparent that underpruning reduced the quality of the fruit as measured by bunch and berry but not as measured by sugar and acid content of the juice.

FIGURE 2. Upper row:— 3 typical bunches of the 1936 crop from Plot C10—a very weakly vegetative plot having an average of 1.1 lbs. of prunings per vine in January 1936. Sugar and acid content of the juice from this plot in 1936 were 18.2 and 0.58% respectively. Lower row:— 3 typical bunches of the 1936 crop from Plot C7—a strongly vegetative plot having an average of 3.4 lbs. of prunings per vine in January. 1936. Sugar and acid content of the juice from this plot in 1936 were17.0 and 0.69% respectively. Being in the same series the same number of buds per vine had been left at pruning time on each of these plots (54 in 1936).

2. Effect of Applications of Nitrogen, Phosphorus, and Potassium on Wood Growth, Yield, and Quality of Fruit

Wood Growth

TABLE 3.—EFFECT OF FERTILIZERS ON WEIGHT OF PRUNINGS*

—	N	P	K	NP	NK	PK	NPK
1929†	− 2.2	+10.9	+ 3.5	+ 6.6	− 5.0	+ 2.6	− 8.4
1932	−13.3	− 6.3	+ 3.1	+ 4.6	+ 1.4	−10.1	− 0.6
1933	− 8.6	+ 2.9	+ 2.3	+ 6.6	+ 9.5	− 2.2	+ 4.9
1934	− 8.4	+ 2.8	+ 6.8	+ 5.1	+ 2.5	− 7.2	+ 5.5
1935	−10.3	+10.4	+10.7	+20.7	+ 3.7	+ 3.8	+21.9
1936	− 8.9	+10.5	+ 8.2	+16.4	+ 7.7	− 6.4	+16.4
1937	−18.1	+ 1.9	+ 4.8	+18.7	+ 1.7	− 0.2	+17.1

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent untreated plots (A, B and C Series). Figures given for a certain year refer to the growth of the preceding year. In 1930 and 1931 pruning weights were not taken.
† No treatment at this time.

Using 1929 figures as a base the following conclusions seem justified. 1. Nitrate of soda has decreased growth to a slight extent. 2. Superphosphate alone and sulphate of potash alone have not increased growth. 3. All combinations containing nitrate of soda seem to have increased growth to a slight extent, the NPK combination being most useful. 4. The phosphate-potash combination has been ineffective.

On all phosphate plots weed growth has been stimulated, which is an indication that phosphate might be applied to advantage to increase the growth of green manure crops.

Yield

TABLE 4.—EFFECT OF FERTILIZERS ON YIELD OF FRUIT*

—	N	P	K	NP	NK	PK	NPK
1929	−1.7	+ 4.8	+3.5	+ 1.9	+ 3.6	− 1.1	+ 0.5
1930	−3.0	+ 0.2	−1.5	+ 5.2	+ 3.3	+ 3.2	− 0.4
1931	−0.4	+ 3.2	+2.4	− 0.9	+ 6.9	+ 3.0	+ 4.7
1932	−0.8	+ 2.3	+6.2	+ 2.4	+ 6.0	+ 1.3	+ 1.8
1933	+1.2	+ 4.8	+7.5	+ 5.1	+10.1	+ 8.6	+ 8.4
1934	−5.3	+ 5.2	+3.4	− 0.7	+ 5.9	+ 7.9	+ 8.2
1935	+2.9	+10.0	+3.1	+ 5.3	+ 8.0	+11.4	+ 5.2
1936	−7.8	+ 3.1	+5.9	+11.2	+12.3	+ 7.1	+10.5

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent untreated plots (A, B and C Series).

In a general way the comparative yields of fruit from the various treatments present a close parallel to the wood growth (Table 2). In 1936, the greatest increase in yield of fruit, which resulted from the NPK treatment, was 10%. At prevailing prices of fertilizer and grapes 10% increase in crop is not nearly enough to pay for the fertilizer and its application in the amounts noted in Figure 1. However, knowing that the soil is very low in readily available phosphorus and approaching a deficiency in replaceable potassium, one would expect that the effect of fertilization would last for many years and thus show a profit eventually.

Quality of Fruit

TABLE 5.—EFFECT OF FERTILIZERS ON PERCENTAGE SUGAR IN THE JUICE*

—	N	P	K	NP	NK	PK	NPK
1930	+1.0	−1.3	−4.3	−4.8	−1.3	−6.2	+2.8
1931	+1.1	+2.5	−1.6	−2.4	+1.3	−0.7	+3.7
1932	+2.2	+2.6	+1.4	+0.2	+2.7	+2.8	0
1933	+2.2	+1.2	−1.2	−1.5	+0.8	+0.3	−1.7
1934	+0.4	+0.1	−1.3	−1.0	+0.4	+3.3	+0.4
1935	−1.5	−0.2	−0.9	−0.8	+0.7	+1.1	+0.7
1936	+0.5	+0.8	−2.2	−3.4	+0.5	+0.2	−1.4

* Each figure represents the mean percentage increase or decrease of 6 treated plots from their adjacent check plots (A, B and C Series). Two samples were taken from each plot at intervals of about 11 days.

TABLE 6.—EFFECT OF FERTILIZERS ON PERCENTAGE TOTAL ACIDS IN THE JUICE*

—	N	P	K	NP	NK	PK	NPK
1930	−1.9	+1.6	+0.8	−0.6	−1.1	+0.2	−2.3
1931	−1.0	−0.7	+0.2	+0.6	+0.5	−0.3	−0.5
1932	−5.1	−3.8	+3.8	+3.8	−0.2	−0.7	−1.2
1933	−3.1	+2.1	+4.5	+2.3	+0.9	−3.0	+1.6
1934	−2.0	+3.1	+4.3	+4.5	+2.2	+1.7	+1.2
1935	−2.6	+4.3	+4.0	+5.4	+0.4	+1.7	+2.9
1936	−3.1	+1.8	+7.7	+4.5	−0.2	+1.7	−0.7

* Each figure represents the mean percentage increase or decrease of six treated plots from their adjacent check plots (A, B and C Series). Two samples were taken from each plot at intervals of about 11 days.

From an examination of Tables 5 and 6 it is obvious that if any fertilizer has had an effect on the sugar and acid content of the juice it has been a very minor one and of no commercial importance. This result is in accord with the findings of Gladwin (3).

Effect of Applications of Straw and Lime, and the Growing of Green Manure Crops on Wood Growth, Yield, and Quality of Fruit

Wood Growth

TABLE 7.—EFFECT OF VARIOUS SOIL TREATMENTS ON WEIGHT OF PRUNINGS*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-October	Muriate of potash
1931	− 1.3†	−14.9†	+12.0	+16.7	−3.8†	+6.3
1933	+15.2	+ 7.1	+ 6.3	+11.4	+2.3	−4.9
1934	+31.3	+ 9.4	+ 7.6	+16.7	+5.0	+3.4
1935	+38.6	+20.2	+21.6	+15.8	+2.7	+4.6
1936	+37.7	+22.6	+17.7‡	+20.9‡	+4.6‡	+4.2
1937	+30.9	− 9.5	+33.3	+14.5	+6.1	+4.8

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D series). In 1932 pruning weights were not recorded.
† No treatment at this time.
‡ Limed—no nitrogen added after 1935.

As in A, B and C Series there was no increased growth from applications of nitrate of soda, but in contrast there seemed to be no decrease in growth in D series. There seemed to be no object in continuing to use nitrogen in D series, and as many growers are using lime or a lime-carrying fertilizer it seemed wise to change the nitrogen plots to lime plots; therefore in the spring of 1935 hydrated lime was applied to these 6 plots at the rate of 1500 lbs. per acre. Up to the present no more lime has been applied to these plots. At the present time there appears to be no appreciable effect from lime either one way or the other. As with sulphate of potash alone on A, B and C Series, muriate of potash alone (D Series) appears to have been ineffective.

By far the most marked response from any treatment in this experiment is that resulting from additions of organic matter. Straw plus nitrate has given the greatest growth increase but green manure crops have been a close second. Even though the growth of green manure crops, mostly Japanese Millet, has been rather poor, averaging about 15 inches in height, the response in vine growth has been considerable. The falling-off in 1936 growth (1937 prunings) was probably due entirely to the rye crop being left standing too long.

Yield

TABLE 8.—EFFECT OF VARIOUS SOIL TREATMENTS ON YIELD OF FRUIT*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930	+ 3.2†	− 9.5†	+ 6.7	+ 4.5	+5.4†	+ 5.7
1931	+ 0.4	− 3.3	− 1.4	− 1.6	+6.1	− 3.8
1932	+12.4	+ 1.1	+ 2.0	+ 2.8	+9.8	+12.2
1933	+ 5.7	+ 2.9	+ 5.1	+ 5.5	+9.7	+ 0.3
1934	+13.8	+ 1.1	− 0.5	+ 1.6	−3.0	+ 8.1
1935	+16.5	+ 6.6	+13.4‡	+ 7.2‡	+6.5‡	+11.3
1936	+24.3	+ 1.3	+ 8.0	+11.8	+2.8	+ 6.4

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check lots (D series).
† No treatment at this time.
‡ Limed—no nitrogen added after 1934.

Effects of the various treatments in D series on yield of fruit (Table 8) are very similar to the effects on wood growth (Table 7) but of slightly lower proportions, *i.e.*, fruit production has not quite kept up with growth increases even though, beginning in 1935, D series has been pruned according to vigour using Partridge's recommendations (6). Although no straw has been applied since the fall of 1934 the straw plots have continued to show larger yield increases. The drop in relative yield from the green manure plots in 1936 can almost be attributed to the rye crop being left standing too long. Up to the present time it is doubtful if the straw plus nitrogen has been a profitable practice but if these plots continue to produce heavier crops than the check plots, without further additions of straw and nitrogen, a profit will be realized. The green manure crops have been profitable as the cost of seed and seeding has been small. Lime applied in the spring of 1935 has had no appreciable effect on the 1935 and 1936 crops, and muriate of potash, like sulphate of potash in A, B and C series, has not increased yields when used alone.

Quality of Fruit

TABLE 9.—EFFECT OF VARIOUS SOIL TREATMENTS ON PERCENTAGE SUGAR IN THE JUICE*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930			+0.7	+0.5		+0.7
1931	−5.1	−1.9	+0.6	−9.8	+2.3	−3.1
1932	−2.7	+0.4	−2.1	−2.5	−1.7	−0.5
1933	−4.2	−2.0	−2.3	−0.9	−0.8	−0.5
1934	−3.0	+0.2	+0.5	+1.0	+1.4	+4.0
1935	−6.1	−3.2	−5.9†	−3.2†	−4.6†	−0.9
1936	−3.0	+0.4	−1.1	−2.0	+0.5	+1.3

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D Series). Two samples were taken from each plot at intervals of about 11 days.
† Limed—no nitrogen added after 1935.

TABLE 10.—EFFECT OF VARIOUS SOIL TREATMENTS ON PERCENTAGE TOTAL ACIDS IN THE JUICE*

—	Straw +N	Green manure	N mid-April	N mid-May	N late-Oct.	Muriate of potash
1930			− 0.2	+4.0		+5.9
1931	+3.4	+0.4	+ 2.0	+1.6	−0.9	+1.5
1932	+8.1	+2.8	+ 4.8	+9.3	+0.8	+2.5
1933	+7.8	+6.5	+ 5.4	+8.8	+4.1	−0.5
1934	+5.0	+7.7	+ 5.5	+4.2	+0.9	+1.8
1935	+6.1	+4.8	+13.4†	+6.1†	+7.1†	+4.7
1936	−0.8	+1.9	+ 4.1	+2.7	+0.8	+6.0

* Each figure represents the mean percentage increase or decrease of two or three treated plots from their adjacent check plots (D series). Two samples were taken from each plot at intervals of about 11 days.
† Limed—no nitrogen added after 1935.

A survey of the results given in Tables 9 and 10 shows no consistent or significant effects of added organic matter, lime, nitrate of soda or muriate of potash on the quality of the fruit as measured by sugar and acid content.

Changes in Sugar and Acid Content of the Juice in the Final Stages of Ripening

In taking two samples from each plot each year at an average interval of 11 days an excellent opportunity was afforded to measure the changes in sugar and acid content of the juice as ripening progressed. It is known that grapes improve in taste up to the normal cutting season and the average person considers that this improvement is due mainly to increased sugar content. Our results, 1930–36, indicate that there is much greater improvement in quality by means of reduction in total acid content as the following figures show.

	First test	Second Test (11 days later)	
Mean percentage sugar	14.7	15.5	= 5.4% increase
Mean percentage total acids	.74	.61	= 17.6% decrease

Effects on the Soil of Applications of Fertilizers, Lime, and Organic Matter

Soil samples were taken from each plot in A, B and C Series in the spring of 1929, spring of 1934 and in the fall of 1936. Samples from D Series were taken in 1930 instead of 1929. Each surface sample was a composite of 6 equally distributed borings and each subsurface sample, 4 borings. On the average surface samples were from the top 6 inches and subsurface samples, from the second 6 inches. Unfortunately a number of the 1930 samples of D Series were ruined for analytical purposes. 1934 samples were used only for phosphorus tests.

Readily Available Phosphorus

TABLE 11.—READILY AVAILABLE PHOSPHORUS (P.P.M.) $KHSO_4$ METHOD. MEANS OF 6 PLOTS IN A, B AND C SERIES*

Treatment	Surface			Subsurface		
	1929 spring	1934 spring	1936 fall	1929 spring	1934 spring	1936 fall
N	39	47	49	27	30	35
P	**33**	86	**80**	**30**	37	**54**
K	28	35	38	21	35	27
NP	**29**	64	**89**	33	27	37
NK	26	36	41	28	26	28
PK	**19**	69	**62**	34	24	33
NPK	**28**	66	**87**	27	18	33
Untreated (27 plots)	32	39	45	37	29	32

* 1929 and 1936 figures of a given treatment in boldface type represent significant differences (Student's method).

Over the 8-year period a total of 5600 lbs. per acre of superphosphate, alone and in combination, was applied. It is very evident that these amounts have significantly increased the readily available phosphorus in the surface soil, but the increase in the subsurface soil has been insignificant except where superphosphate was used alone. It is a well known fact that phosphates tend to remain in the top soil, and therefore it is not surprising that the subsurface soil shows little increase. As cultivation and drouth conditions tend to discourage root growth in the top soil it is quite possible that the grape roots may still be more or less starved for phosphorus as the figures for the subsurface soil represent a low level of phosphorus. Below 40 p.p.m. is considered insufficient for grain crops but the line between deficiency and sufficiency for the grape is not known. No explanation can be offered for the increase of readily available phosphorus in the surface soil and decrease in the subsurface soil of the untreated plots.

While the number of samples is scarcely enough to yield definite conclusions one is probably justified in saying that added organic matter, lime and muriate of potash have not materially altered the supply of readily available phosphorus (Table 12) except for the decrease in the subsurface samples from the muriate of potash plots. This marked decrease cannot be explained. That hydrated lime applied in the spring of 1935 has had no effect one way or the other is of particular interest.

TABLE 12.—READILY AVAILABLE PHOSPHORUS (P.P.M.) $KHSO_4$ METHOD. D SERIES

Treatment	No. of plots	Surface		Subsurface	
		1934 spring	1936 fall	1934 spring	1936 fall
Straw + N	3	51	43	46	34
Green manure	3	43	49	41	37
Lime	6	40	41	37	33
Muriate of potash	2	30	28	41	21
Untreated	9	42	42	41	36

Replaceable Potassium

TABLE 13.—REPLACEABLE POTASSIUM (P.P.M.).* MEANS OF 6 PLOTS IN A, B AND C SERIES†

Treatment	Surface		Subsurface	
	1929 spring	1936 fall	1929 spring	1936 fall
N	88	140	94	105
P	111	150	104	137
K	**92**	**240**	82	116
NP	85	111	88	90
NK	**94**	**250**	99	127
PK	**89**	241	96	127
NPK	**78**	**289**	111	136
Untreated (27 plots)	**98**	**135**	97	120

* Truog's modification of the sodium cobaltinitrite method.
† 1929 and 1936 figures of a given treatment in boldface type represent significant differences (Student's method).

For the grain crops about 80 p.p.m. of replaceable potassium is considered the line between deficiency and sufficiency. The potassium needs of the grape are unknown. However, it is evident (Table 13) that some of this area might show a response to potassium fertilization of green manure (grain) crops, though phosphorus appears to be the more deficient of these two elements.

Over the 8-year period a total of 1900 lbs. per acre of sulphate of potash has been applied to the potassium plots. This application has resulted in a very significant increase in replaceable potassium in the surface soil but not in the subsurface soil (Table 13). Increases in the latter are only slightly greater than the increases in the untreated plots; therefore it is very doubtful if any of the applied potassium has reached the subsurface soil. As it is well known that ordinary potassium fertilizers tend to become fixed in the surface soil or at least move slowly to lower levels, this result was not unexpected. No explanation can be offered for the increase of replaceable potassium in the surface and subsurface soils of the unfertilized plots.

Because of the loss of a number of the 1930 samples from D Series there are not sufficient comparisons to warrant conclusions concerning the

effect of the treatments on replaceable potassium, though an effect without significance is indicated except where muriate of potash was applied.

Lime

All of the 1929 and 1930 soil samples were tested for pH, using the quinhydrome electrode. The average pH of the surface soil was 5.51, and of the subsurface soil, 5.84, both generally considered medium acid. A few of the 1936 samples which were tested showed a slight decrease in acidity in the surface soil but no change in subsurface soil. The addition of 1500 lbs. of hydrated lime per acre in the spring of 1934 to six plots in D Series changed the soil reaction to a considerable extent but did not bring the soils to the neutral point. The pH values, means of the 6 lime plots, were as follows:

	Surface	Subsurface
1930	5.86	5.91
1936	6.59	6.20

The 1936 samples from D Series were tested for replaceable calcium, ($KMnO_4$ Method). An average of the readings from all 9 checks was 2013 p.p.m. for surface soil, and 2105 p.p.m. for subsurface soil—a fairly high level for this element. Additions of organic materials and muriate of potash have not appreciably altered the amounts of replaceable calcium and even the 1500 lb. application of hydrated lime has been without effect in changing this level.

Organic Matter

A few of the 1936 samples taken from D Series were tested for organic matter content using Schollenberger's Chromic Acid Method. For surface soils only, the average percentage organic matter was as follows—

6 untreated plots	3.81%
3 straw—N plots	4.40%
3 green manure plots	3.94%

The difference between untreated and green manure plots cannot be considered significant, and the addition of two tons of straw per acre per year for 5 consecutive years has but slightly increased the organic matter content of these plots as measured by the Chromic Acid Method.

DISCUSSION

In this experiment there has been a wide range of vigour in the various plots, and yet the sugar and acid content of the juice of the grapes has not varied sufficiently to warrant the adoption of unusual pruning practices. Apparently the wine and juice manufacturers cannot expect much improvement in the sugar and acid content of the grape juice by alterations in the vigour of the vines. It has been shown, however, that the state of vigour of the vine does affect size of bunch and berry and it may also affect the yield of juice per ton of grapes, a point which our data does not touch. The desirability of a satisfactory balance between growth and fruit production has again been demonstrated. Overpruning results in rampant growth made at the expense of the fruit crop, and underpruning with con-

sequent overbearing results in weak vines very subject to damage from drouth or freezing. In this vineyard a desirable state of vigour seems to be such as will yield from two to three pounds of prunings per vine calling for the retention at pruning time of from 38 to 48 buds.

The failure of nitrate of soda to stimulate growth or fruit production in this vineyard is rather an unusual result for this fertilizer. Evidently nitrogen is not the major limiting factor. Judging by the low level of readily available phosphorus this element may be *the* limiting factor, but not knowing the desirable level of phosphorus for the grape there can be no certainty that this is the case. There is some evidence from foliage symptoms that potassium may be a limiting factor in certain areas. While the analyses indicate that the potassium is not as likely to be a limiting factor as the phosphorus there are some areas which were quite low in replaceable potassium.

Very limited observations indicate that the bulk of the roots are in the subsurface soil, and analyses show that very little of the phosphate and potash applied on the surface and disked in has reached this level. However, the increase in growth and fruiting when phosphate and potash are added to the nitrate indicates some beneficial effect, direct or indirect, from these nutrients. As these effects have been small and slow to appear, and as it has been shown that superphosphate and sulphate or muriate of potash remain largely in the top soil, deep placement of these fertilizers should be tried.

The favourable results from the use of straw plus nitrate and from summer green manure crops are worthy of note. It is probable that an equivalent application of barnyard manure would have given as good or better results than the straw plus nitrate, and it is conceivable that there would be additional advantage from green manure crops if properly fertilized. As weedgrowth has been stimulated by phosphate applications, and as additions of organic materials have had a beneficial effect, the use of phosphate fertilizers with green manure crops would seem advisable.

Because of the favourable response from organic additions to the soil the experiment was altered in 1937 to make the major comparions between alfalfa hay with fertilizers, alfalfa hay without fertilizers, and fertilizers alone, the alfalfa hay being applied in the fall in a finely cut form and ploughed in at once.

CONCLUSIONS

1. Overpruning caused crop reduction but there was some compensation in larger bunches and berries, and, if not carried to an extreme, a slight increase in sugar content of the juice. Extreme overpruning resulted in lower sugar and higher acid in the juice. Underpruning gave small bunches and small berries but the fruit ripened at normal time as measured by the sugar and acid content of the juice. Eventually underpruning resulted in weak vines very subject to injury from drouth and freezing.

2. Improvement in eating quality of the grape during the last few days before cutting time was effected much more by a reduction of acid content than by an increase in sugar content.

3. The soil in this vineyard was found to be very low in readily available phosphorus, low to medium in replaceable potassium, fairly high in replaceable calcium but medium acid in reaction, and medium in organic matter.

4. In this experiment no fertilizer had any appreciable influence on the sugar and acid content of the grape juice. This does not prove, however, that phosphate and potash are without effect since soil analyses have shown that a large part of these fertilizers have remained above the root zone.

5. Nitrate of soda alone was ineffective in increasing growth or fruitfulness and in fact there was a slight depression of growth and fruiting. The increases in yield from the various fertilizer combinations were very small, the combination of nitrate, phosphate and potash giving the greatest response.

6. Additions of organic materials, straw and green manure crops, without phosphate and potash have given marked increases in growth and fruit production.

7. Very little, if any, phosphate and potash applied on the surface has penetrated below the top 6 inches of soil. Limited observations indicate that very few of the roots are to be found in the surface soil therefore the roots may have had very little access to the added minerals.

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VARIETAL RESISTANCE OF WHEAT AND OATS TO ROOT ROT CAUSED BY *FUSARIUM CULMORUM* AND *HELMINTHOSPORIUM SATIVUM*[1]

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INTRODUCTION

The problem of root rot of wheat and other small grains is one of considerable complexity, because several fungi may be involved as causal organisms, alone or in association, and each may be affected by soil, climate, and other factors. The production of resistant varieties would appear to be the most satisfactory method of controlling this important disease of cereals. However, before any particular advance can be made by the plant breeder towards developing varieties that are resistant to root rot, some satisfactory field method has to be found for selecting parental material and testing standard and new varieties. The object of the present investigation was threefold: (1) to develop an accurate method for measuring the amount of disease caused by root-rotting fungi on cereals, (2) to devise practical and efficient methods for producing under field conditions positive attacks of common root rot, and (3) to determine the relative susceptibility of standard varieties and new rust-resistant strains of wheat already produced to *Fusarium culmorum* (W.G.Sm.) Sacc. and *Helminthosporium sativum* P.K. & B., and similarly of oats to *Fusarium culmorum*. The investigation was begun at the Dominion Rust Research Laboratory, Winnipeg, Manitoba, in 1930. Brief reports on the progress of the work have already appeared (3, 4). The purpose of this paper is to summarize the results of field experiments made during the 7-year period 1930 to 1936.

In this paper the descriptive name "root rot" is used to indicate a diseased condition of the base and roots of cereal plants caused by *F. culmorum*, *H. sativum*, and some other fungi. This disease is manifested variously by such symptoms as pre-emergence killing, seedling blight, basal browning, crown rot, foot rot, and root rot. It is widely distributed in the three prairie provinces of Canada, and frequently it is a limiting factor in the production of cereal crops (1). Owing to the extensive scale on which wheat is grown in these provinces, the greatest economic loss from common root rot occurs in this crop.

Before presenting the results with which this paper is mainly concerned, mention should be made of some preliminary experiments made at Winnipeg in 1930 and 1931. In each of these two years 3 field experiments were made to compare the reactions of 40 varieties of wheat, 12 of oat, and 11 of barley to *Fusarium culmorum*, to *Helminthosporium sativum*, and to a miscellaneous group of soil fungi that included these two. The system of replication used in each experiment was 3 randomised blocks of 63 plots each. The seed was inoculated with spores of the fungus or fungi against

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which the varieties were to be tested, and spores and mycelial fragments of the fungus or fungi were added to the soil. Disease and yield data were recorded for each plot, and the data of each experiment were analyzed by the analysis of variance method suggested by Fisher (2).

No significant differences in the degree of resistance to *F. culmorum*, to *H. sativum*, or to the mixed group of fungi were established between varieties in these 2 years. All varieties and selections of wheat tested gave fairly high disease-infection ratings. The variety Mindum and a few selections with Mindum parentage seemed to be slightly more susceptible than the others. No appreciable differences in susceptibility were observed among the oat or the barley varieties.

EXPERIMENTAL METHODS

The results of the preliminary experiments of 1930 and 1931 emphasized a distinct need for more information concerning methods of infesting field plots with cereal root-rot fungi, and led, in 1932, to the establishment of a series of large, permanent, artificially-infested plots (Root-Rot Garden) at Winnipeg, Manitoba. From 1932 to 1935 these plots were used to study the comparative susceptibility of wheat varieties to fungi most commonly associated with root rot in Manitoba. In addition, extensive varietal trials, both with wheat and oats, were made at different stations in Manitoba in 1934, 1935, and 1936.

Root-Rot Garden Tests

The system of replication used in the root-rot garden was 6 randomised blocks of 4 large plots each. In 1932, and in each of the 3 succeeding years, each of the 4 plots received a different treatment, but in all 4 years a plot received the same treatment. The treatments were as follows: (1) soil and seed artificially infested with *F. culmorum*; (2) soil and seed artificially infested with *H. sativum*; (3) soil and seed artificially infested with the miscellaneous group of fungi; (4) soil and seed not infested artificially (control).

Each large plot was divided into 24 variety sub-plots. A sub-plot consisted of 2 rod-rows placed one foot apart. In one row a predetermined quantity of seed, depending on the variety, was sown, while 100 kernels of the same variety were sown, spaced about 2 inches apart, in the other row. The former row furnished data relative to yield, the latter data on the amount of disease.

Twenty varieties of wheat, two of oats, and two of barley were tested in each large plot of the root-rot garden in 1932 and 1933. In 1934 and 1935 twenty-four wheat varieties were tested in each plot. The varieties and selections of cereals used were secured from the Cereal Division, Dominion Rust Research Laboratory, Winnipeg, Manitoba.

Varietal-Susceptibility Trials

Field trials to determine the behaviour of several standard varieties and a large number of rust-resistant strains of wheat to root rot under artificially-induced and natural epidemics of this disease in Manitoba were begun in 1934. Similar trials were made in 1935 and 1936. The varieties and strains used were those selected by the Subcommittee on Plant

Breeding[5] for co-operative tests in Western Canada. The wheat varieties, 36 in 1934, 28 in 1935, and 22 in 1936, were tested at Winnipeg in plots artificially infested in one-half with *F. culmorum*. In addition to the Winnipeg trials, the same varieties were tested in 1934 at Brunkild in soil naturally infested with *H. sativum*. The varieties of the 1935 and 1936 experiments were tested at Winnipeg and also in fields naturally infested with *F. culmorum* at Souris and Whitewater. In 1934, 1935, and 1936, ten varieties of oats were tested at Winnipeg in plots artificially infested in one-half with *F. culmorum*.

The system of replication used in the Winnipeg experiments was 4 or 6 randomised blocks of a number of plots each, the number of plots depending on the number of varieties in the test. One-half of each plot, a variety sub-plot, was infested artificially with *F. culmorum*, while the soil of the other portion of the plot remained in the natural condition. Each sub-plot consisted of two rod-rows. The arrangement of rows was similar to that used in the root-rot garden tests, as already described. The disposition of varieties and soil treatments (artificially and naturally-infested soil) was purely at random within each block. All experiments conducted in the naturally-infested fields at Brunkild, Souris, and Whitewater, consisted of 4 or 6 randomised blocks of a large number of variety-plots each.

Details concerning the technique of infesting the soil of field plots with cereal root-rot fungi have already been described (4). Briefly stated, the method consists of applying to the soil an inoculum consisting of finely-ground oat hulls overgrown with the fungus or fungi to be introduced, and of inoculating the seed before planting by dipping it in a suspension of spores and mycelial fragments of the respective fungus, or fungi.

The strains of *F. culmorum* and *H. sativum* used for artificial infestation of the seed and of the soil were originally isolated from diseased roots of wheat plants. Previous tests (4), both in the greenhouse and in the field, had demonstrated that these fungi were definitely pathogenic to wheat. The strain of *F. culmorum* used was pathogenic also to oats.

Germination was usually complete 30 days after sowing, at which time the number of emerged plants in the spaced-seed row of each sub-plot was counted. About 10 days before full maturity, while the crop was still green, the plants in the spaced-seed row of each variety plot were lifted from the soil, examined individually, and the extent of root-rot infection on each plant recorded. In all tests herein reported a disease-rating method was used to express the extent of root-rot occurring in each variety plot. The classes and numerical ratings used to record the intensity of disease infection on individual plants of each plot, and the method of computing the disease rating, are presented in Table 1. The yield of a variety was secured by harvesting one rod row of each sub-plot and recording the weight of the threshed grain. Separate records for plant emergence,

[5] Subcommittee on Plant Breeding, Associate Committee on Field Crop Diseases (Western Section), National Research Council and Dominion Department of Agriculture, Canada.

disease rating, and yield were recorded, and the data were analyzed by the procedure described by Fisher (2) as the analysis of variance. To estimate the odds of significance, however, the F value of Snedecor (7) was used.

TABLE 1.—CLASSES, NUMERICAL RATINGS, AND DISEASE RATING USED TO RECORD THE DEGREE OF INFECTION BY *Fusarium* CULMORUM AND *Helminthosporium sativum* ON CEREAL PLANTS

Class	Degree of infection on individual plants	Numerical rating
1	No infection	0
2	Small, scattered necrotic lesions on sheath, subcrown internode, or roots	1
3	Distinct, dark lesions on basal parts, particularly on subcrown internode and roots	2
4	Large necrotic lesions on crown, subcrown internode, and roots; with loss of plant vigour	3
5	Severe rotting of basal parts; plant chlorotic, often wilted or stunted; some culms dead	4
6	Plant failed to emerge, or killed before maturity. Dead plant	5

$$\text{Disease rating} = \frac{\text{Sum of numerical ratings of individual plants} \times 100}{\text{Number of seeds sown} \times 5}.$$

The results of the various experiments are presented in the form of summary tables. These tables give the mean value of individual varieties, or the mean value of all varieties in an experiment, with an associated standard error by which differences may be compared. In this paper the difference between two quantities having the same standard error is considered significant if it is three times that standard error.

EXPERIMENTAL RESULTS

Relation of Root-Rot Infection Rating to Yield in Wheat

During the period 1931–35, special experiments were made each year to discover whether or not the amount of root-rot infection, as represented by the disease rating, was associated with yield, and to ascertain the reliability of this method of recording the intensity of root-rot infection on cereal varieties under field conditions. A short report of the earlier experiments appeared in 1934 (4). In each experiment a single standard variety of wheat was employed, and the amount of root rot in individual plots was varied by the employment of different devices to introduce pathogenic fungi into the soil. In the final analysis of the results of each experiment, disease ratings and yields of individual plots were correlated. The significance of the correlation coefficients so obtained was determined by the method described by Fisher (2).

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TABLE 2.—CORRELATION SURFACE SHOWING THE RELATION BETWEEN ROOT-ROT DISEASE RATING AND YIELD IN MARQUIS WHEAT. ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum*

Yield (bus. per acre) \ Disease Rating	50	53	56	59	62	65	68	71	73	76	79	82	85	88	91	94	97	Freq.
3																1	1	2
5																4	9	13
7																3	4	7
9		1														2	1	4
11											1					2	2	5
13								1		1		1	1				1	5
15								1				1						2
17					1		1				2	1						5
19								1			1							2
21			1			1	2				1							5
23						1	1		1			2						5
25										1								1
27	1				1				1									3
29																		0
31				1														1
Freq.	1	1	1	1	2	2	4	3	2	2	5	5	1	0	0	12	18	60

$r_{xy} = -0.8052$

$t = 10.34$ 1% point = 2.57

In Table 2 a correlation surface is illustrated. This shows the distribution of disease ratings and yields of 60 plots of Marquis wheat that were artificially infested with *F. culmorum* in 1933. The distribution of disease ratings and yields of 60 plots of Marquis wheat artificially infested with *H. sativum* in 1933, is illustrated in Table 3. The results of the statistical study of the data of all experiments made during the five years 1931 to 1935 are summarized in Table 4.

The results in Table 4 clearly establish the fact that root rot caused by *F. culmorum* and *H. sativum* has a very detrimental effect on the yield of wheat. Significant negative correlations were obtained in all experiments. Thus it appears that increases in the degree of root-rot infection, as expressed by the disease rating, result in decreases in yield. Considering the wide variations that occurred in replicated field plots, and the difficulties encountered in some years in producing artificially epidemics of root rot in the field, the correlations in Table 4 are very significant. From these results it was concluded that the disease rating is very closely related

TABLE 3.—CORRELATION SURFACE SHOWING THE RELATION BETWEEN ROOT-ROT DISEASE RATING AND YIELD IN MARQUIS WHEAT. ARTIFICIAL INFESTATION OF THE SOIL WITH *Helminthosporium sativum*

Yield (bus. per acre)	Disease Rating 56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	Freq.
12															1			1
13																		0
14												1		1			1	3
15									1			1			1			3
16						1			1				2					4
17						1	1			1	1	1	3	2				10
18								1		1	1	2	1	1				7
19						1					2			1				4
20								1	1			1	1					4
21							1	1	2	1	1		1	1				8
22										2	1	2	1					6
23						1												1
24																		0
25			1	1														2
26						1	1	1										3
27					1			1										2
28	1							1										2
Freq.	1	0	1	1	1	5	3	6	5	5	6	8	9	6	2	0	1	60

$r_{zy} = -0.6223$

$t = 6.05$ 1% point = 2.57

TABLE 4.—CORRELATION BETWEEN THE DEGREE OF ROOT-ROT INFECTION, AS EXPRESSED BY THE DISEASE-RATING METHOD, AND YIELD IN WHEAT

Year	Variety	Tested against	Correlation coefficient	t*
1931	Mindum	*F. culmorum* and *H. sativum*	−0.52	4.47
1931	Marquis	*F. culmorum* and *H. sativum*	−0.32	2.48
1932	Mindum	*F. culmorum* and *H. sativum*	−0.63	5.93
1932	Marquis	*H. culmorum* and *H. sativum*	−0.69	6.22
1933	Marquis	*F. culmorum*	−0.80	10.34
1933	Marquis	*H. sativum*	−0.62	6.05
1934	Pentad × Marquis	*F. culmorum*	−0.55	4.96
1935	Pentad × Marquis	*F. culmorum*	−0.37	3.07

*5% point = 1.95. 1% point = 2.57.

to yield, and constitutes an accurate measure of the amount of root rot in wheat. The disease rating was therefore considered sufficiently reliable to be employed in estimating the field reactions of varieties and selections of cereals to root rot caused by *F. culmorum* and *H. sativum*.

Infection in Field Plots

The preliminary experiments of 1930 and 1931 demonstrated that naturally-infested soil would be most suitable to determine the relative susceptibility of cereal varieties to root-rot caused by *F. culmorum* and *H. sativum*. As it was found difficult to secure each year suitable naturally-infested fields for experimental purposes, it was necessary, in order to make satisfactory annual root-rot tests, to develop an efficient and a practical technique for inducing positive attacks with *F. culmorum* and *H. sativum* in field plots. The results of experiments in which positive attacks with *F. culmorum* have been artificially induced in plots of wheat have appeared in an earlier paper (4). The results obtained in the present root-rot garden tests and varietal trials are summarized here. Earlier in this paper, reference was made to treatment of the soil.

Root-Rot Garden Tests

A complete analysis of variance for plant emergence, disease rating, and yield was made for the root-rot garden tests of 1932, 1933, 1934, and 1935. The analyses in Tables 5 and 6 establish significant differences, both with respect to number of plants emerged and disease rating, between the 4 soil treatments used in the root-rot garden. In every case the *F* values for soil treatments are much greater than the 1% probability values. An examination of the yield data (Table 7) shows that significant differences in yield for soil treatments were not obtained in 1932 and 1933. In 1934 and 1935, however, these yield differences were highly significant. A summary of the mean results of all wheat varieties tested annually in the root-rot garden during the 4 years 1932–35, with the standard errors associated with them, showing the effect of artificial infestation of field plots on plant emergence, disease rating, and yield, are given in Table 8.

The results in Table 8 show that even though inoculum of a root-rotting fungus was not added to the seed or to the soil (control), a considerable amount of infection occurred on the roots and basal parts of wheat plants. In each year of the test the number of plants that emerged in the 100-seed rows of the natural-soil plots in the root-rot garden was quite low, and the degree of root-rot infection in these plots was relatively severe. Thus it would appear that fungi pathogenic to the roots and basal parts of wheat plants naturally inhabit the soil and cause considerable injury to wheat crops. However, as Table 8 shows, plant emergence was markedly reduced and the amount of root-rot considerably increased by infesting the soil artificially with *F. culmorum*, or with the miscellaneous group of fungi (*F. culmorum*, *H. sativum*, *Fusarium* spp., and others).

In 1932 and 1933 the yield of wheat was not influenced by the introduction of pathogenic fungi into the soil, but, in 1934 and 1935, significant differences in yield between the control plots and those artificially infested with *F. culmorum* or with the miscellaneous group of fungi were obtained.

TABLE 5.—ANALYSES OF VARIANCE FOR PERCENTAGE PLANT EMERGENCE IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	7,453.1	1,242.2		
	Soil treatments	3	17,753.9	5,917.9	15.11	6.55
	Error (a)	10	3,914.4	391.4		
	Total	19	29,121.4			
	Varieties	19	26,757.5	1,408.3	23.17	1.85
	Varieties × soil treatments	57	7,393.9	129.7	2.13	1.14
	Error (b)	304	18,476.4	60.7		
	Total	380	52,627.8			
1933	Controlled error	8	2,733.2	341.6		
	Soil treatments	3	70,321.1	23,440.4	124.9	5.95
	Error (a)	12	2.250.6	187.5		
	Total	23	75,304.9			
	Varieties	19	29,385.3	1,546.6	26.98	1.84
	Varieties × soil treatments	57	8,373.2	146.9	2.56	1.11
	Error (b)	380	21,783.5	57.3		
	Total	456	59,542.0			
1934	Controlled error	8	30,348.3	3,793.5		
	Soil treatments	3	82,619.1	27,539.7	53.51	5.95
	Error (a)	12	6,175.0	514.6		
	Total	23	119,142.4			
	Varieties	23	14,856.4	645.9	8.22	1.83
	Varieties × soil treatments	69	5,261.4	76.2	—	1.08
	Error (b)	460	36,142.2	78.6		
	Total	552	56,260.0			
1935	Controlled error	8	10,030.8	1,253.8		
	Soil treatments	3	118,764.7	39,588.2	61.49	5.95
	Error (a)	12	7,725.1	643.8		
	Total	23	136,520.6			
	Varieties	23	8,928.6	388.2	6.47	1.83
	Varieties × soil treatments	69	12,518.9	181.4	3.02	1.08
	Error (b)	460	27,587.2	59.9		
	Total	552	49,034.7			

In all years, plots infested with *H. sativum* yielded slightly less than did the natural-soil controls, but the difference observed each year was not significant statistically. In 1934 the average yield of 24 wheat varieties was decreased 6.5 bushels per acre by artificial infestation of the soil with *F. culmorum*.

An examination of the analyses of variance for yield (Table 7), and to some extent for plant emergence (Table 5), and of the summarized

TABLE 6.—ANALYSES OF VARIANCE FOR ROOT-ROT DISEASE RATING IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	5,200.4	866.7		
	Soil treatments	3	7,489.6	2,496.5	11.49	6.55
	Error (a)	10	2,173.8	217.3		
	Total	19	14,863.8			
	Varieties	19	10,156.6	534.5	16.91	1.85
	Varieties × soil treatments	57	3,317.8	58.2	1.84	1.14
	Error (b)	304	9,615.8	31.6		
	Total	380	23,090.2			
1933	Controlled error	8	2,277.0	284.6		
	Soil treatments	3	31,068.8	10,356.2	150.96	5.95
	Error (a)	12	823.9	68.6		
	Total	23	34,169.7			
	Varieties	19	10,628.6	559.4	17.59	1.84
	Varieties × soil treatments	57	3,092.2	54.2	1.70	1.11
	Error (b)	380	12,105.7	31.8		
	Total	456	25,826.5			
1934	Controlled error	8	13,924.9	1,740.6		
	Soil treatments	3	32,013.9	10,671.3	33.13	5.95
	Error (a)	12	3,864.8	322.1		
	Total	23	49,803.6			
	Varieties	23	5,446.3	236.8	7.76	1.83
	Varieties × soil treatments	69	2,521.2	36.5	1.19	1.08
	Error (b)	460	14,018.6	30.5		
	Total	552	21,986.1			
1935	Controlled error	8	5,924.2	740.5		
	Soil treatments	3	47,644.0	15,881.3	137.62	5.95
	Error (a)	12	1,384.9	115.4		
	Total	23	54,953.1			
	Varieties	23	4,416.6	192.0	6.50	1.83
	Varieties × soil treatments	69	4,430.8	64.2	2.17	1.08
	Error (b)	460	13,588.7	29.5		
	Total	552	22,436.1			

results in Table 8, indicates that there was a progressive annual increase from 1932 to 1935 in the amount of root-rot occurring in plots infested artificially with *F. culmorum*. A similar increase occurred in plots infested artificially with the mixed group of fungi. Unfortunately, the root-rot garden tests were not designed to determine the pathogenic effect on wheat of individual organisms of this mixed group of fungi. Thus, no evidence was produced from the tests to show that any fungus of the mixed group, other than *F. culmorum*, was responsible for the progressive annual increase

TABLE 7. ANALYSES OF VARIANCE FOR YIELD IN WHEAT VARIETIES. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1932	Controlled error	6	3,841.7	640.3		
	Soil treatments	3	306.8	102.3	0.92	6.55
	Error (a)	10	1,116.8	111.7		
	Total	19	5,265.5			
	Varieties	19	9,711.8	511.1	15.25	1.85
	Varieties × soil treatments	57	1,996.5	35.0	1.04	1.14
	Error (b)	304	10,186.6	33.5		
	Total	380	21,894.9			
1933	Controlled error	8	682.4	85.3		
	Soil treatments	3	1,511.7	503.9	3.83	5.95
	Error (a)	12	1,576.1	131.3		
	Total	23	3,770.2			
	Varieties	19	6,482.4	341.2	28.67	1.84
	Varieties × soil treatments	57	2,024.4	35.5	2.98	1.11
	Error (b)	380	4,521.9	11.9		
	Total	456	13,028.7			
1934	Controlled error	8	5,167.1	645.9		
	Soil treatments	3	8,130.9	2,710.3	9.55	5.95
	Error (a)	12	3,403.7	283.6		
	Total	23	16,701.7			
	Varieties	23	19,013.1	826.6	12.97	1.83
	Varieties × soil treatments	69	2,084.4	30.2	0.47	1.08
	Error (b)	460	29,337.6	63.7		
	Total	552	50,435.1			
1935	Controlled error	8	691.9	86.5		
	Soil treatments	3	1,941.3	647.1	32.51	5.95
	Error (a)	12	239.3	19.9		
	Total	23	2,872.5			
	Varieties	23	29,369.4	1,276.9	77.85	1.83
	Varieties × soil treatments	69	2,198.8	31.8	1.93	1.08
	Error (b)	460	7,550.2	16.4		
	Total	552	39,118.4			

in the amount of root rot observed in plots infested annually with this group of fungi during the four years 1932–35.

Varietal-Susceptibility Trials

Further information concerning the effectiveness of the methods used to produce positive root-rot attacks on wheat with *F. culmorum* was provided by the results of the varietal tests made at Winnipeg in 1934, 1935, and 1936. In these tests one-half of each variety plot was artificially infested with

TABLE 8.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum*, WITH *Helminthosporium sativum*, AND WITH A MISCELLANEOUS GROUP OF ROOT-ROTTING FUNGI ON PLANT EMERGENCE, INCIDENCE OF DISEASE, AND YIELD OF WHEAT. ROOT-ROT GARDEN STUDIES, WINNIPEG, 1932–35

Soil infested with	1932	1933	1934	1935
	Percentage of plants emerged*			
Fusarium culmorum	40	32	27	32
Miscellaneous fungi	44	32	25	32
Helminthosporium sativum	52	55	48	61
Control (ordinary soil)	57	57	51	61
Standard error	±1.98	±1.25	±1.89	±2.11
	Disease rating*			
Fusarium culmorum	73.1	81.0	76.4	80.8
Miscellaneous fungi	70.3	80.7	73.7	82.0
Helminthosporium sativum	65.0	65.8	61.7	63.5
Control (ordinary soil)	62.2	63.9	59.1	63.0
Standard error	±1.47	±0.76	±1.49	±0.89
	Yield (bus. per acre)*			
Fusarium culmorum	31.0	15.3	25.9	12.3
Miscellaneous fungi	32.5	16.1	23.4	11.9
Helminthosporium sativum	31.3	18.7	31.4	15.4
Control (ordinary soil)	33.1	19.6	32.4	16.1
Standard error	Insign.	Insign.	±1.40	±0.37

* Each value represents the mean of 20 varieties (120 plots) in 1932 and 1933, and 24 varieties (144 plots) in 1934 and 1935.

F. culmorum, as already described under experimental methods. An analysis of the separate data of each test was made. For the sake of brevity, however, all the analyses are not reproduced. Those given in Table 9 are only the analyses for disease rating and for the different years. The mean results of these varietal tests, showing the effect of artificial infestation of the soil with *F. culmorum* on the number of plants emerged, degree of root-rot infection, and yield, are summarized in Table 10.

An examination of Table 9 shows that significant differences in disease rating for soil treatments (artificially and naturally-infested soil) were obtained in 1934, 1935, and 1936. In every instance the variance for soil treatments was much greater than the variance for error, the *F* value being very much larger than the 1% probability value. Separate analyses of the plant emergence and yield data of these experiments similarly established wide and significant differences between artificially-infested plots and natural-soil controls.

The results in Tables 8 and 10 show that positive attacks of root-rot were induced each year by inoculating the seed and infesting the soil with *F. culmorum*. Statistically, the effectiveness of this method of inducing positive attacks of common root-rot in field plots was established with a

TABLE 9.—ANALYSES OF VARIANCE FOR ROOT-ROT DISEASE RATING IN WHEAT. VARIETAL TESTS, WINNIPEG, 1934–36

Year	Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
1934	Controlled error	7	4,133.3	590.4		
	Varieties	35	4,163.5	118.9	1.86	1.39
	Error (a)	101	6,447.9	63.8		
	Total	143	14,744.7			
	Soil treatments	1	15,558.4	15,558.4	270.11	6.90
	Varieties × treatments	35	1,044.9	29.8		
	Error (b)	108	6,223.2	57.6		
	Total	144	22,826.5			
1935	Controlled error	7	91.8	13.1		
	Varieties	27	9,892.4	366.3	51.24	1.47
	Error (a)	77	550.7	7.1		
	Total	111	10,534.9			
	Soil treatments	1	4,576.5	4,576.5	829.09	6.96
	Varieties × treatments	27	1,669.4	61.8	11.20	1.47
	Error (b)	84	464.1	5.5		
	Total	112	6,710.0			
1936	Controlled error	3	598.5	199.5		
	Varieties	21	3,853.7	183.5	10.08	2.12
	Error (a)	63	1,150.5	18.2		
	Total	87	5,602.7			
	Soil treatments	1	371.4	371.4	35.03	7.01
	Varieties × treatments	21	636.9	30.3	2.85	2.07
	Error (b)	66	706.0	10.6		
	Total	88	1,714.3			

high degree of probability. The results of the root-rot garden tests (Table 8), and of the Winnipeg varietal tests (Table 10), show that root-rot caused by *F. culmorum* has a very detrimental effect on the yield of wheat. As in previous studies (4), the results with *H. sativum* were not satisfactory. Contrary to the results obtained by Sallans (6) in Saskatchewan, all methods used in the present investigation failed to give a satisfactory epidemic of *Helminthosporium* root rot in field plots of wheat. Further experiments to determine the cause of these failures in Manitoba with *H. sativum* are required.

The mean squares for disease rating obtained for the interaction of soil treatments and varieties in the root-rot garden tests (Table 6), and in the variety tests (Table 9), indicate, in general, that wheat varieties behave differently under various conditions of soil treatment. The nature of the conditions that bring about this differential effect of soil treatment on wheat varieties is not at present clear.

TABLE 10.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *F. culmorum* ON PLANT EMERGENCE, INCIDENCE OF DISEASE, AND YIELD OF WHEAT. VARIETAL TESTS, WINNIPEG, 1934–36

Soil treatment	1934	1935	1936
	Percentage of plants emerged*		
Artificially infested with *F. culmorum*	32.7	32.3	51.9
Control (natural soil)	54.0	69.4	66.5
Decrease due to *F. culmorum*	21.3	37.1	14.6
Standard error	±0.94	±0.69	±0.94
	Disease rating*		
Artificially infested with *F. culmorum*	69.9	82.7	68.2
Control (natural soil)	55.2	62.0	57.7
Increase due to *F. culmorum*	14.7	20.7	10.5
Standard error	±0.63	±0.51	±0.77
	Yield (bus. per acre)*		
Artificially infested with *F. culmorum*	21.9	7.1	18.5
Control (natural soil)	34.3	16.2	21.4
Decrease due to *F. culmorum*	12.4	9.1	2.9
Standard error	±0.49	±0.22	±0.35

* Each value represents the general mean of 36 varieties (144 plots) in 1934, 28 varieties (112 plots) in 1935, and 22 varieties (132 plots) in 1936.

Behaviour of Wheat Varieties

Varietal Susceptibility

During the four years 1932–35, the susceptibility of a large number of varieties and strains of wheat to various root-rotting fungi were compared in the root-rot garden plots at Winnipeg. In 1934, 1935, and 1936, tests were also made at several stations in Manitoba to determine the behaviour of several standard varieties and a large number of rust-resistant strains of wheat to root-rot under natural field conditions. The results of these varietal trials are given in Tables 11 and 12, and in Figure 1.

To economize space, tables showing the results obtained in the root-rot garden in 1935 and 1936 are not reproduced; those of 1933 and 1934 are presented in Tables 11 and 12. The varieties are arranged in order of resistance to *F. culmorum*, and numbers are assigned to them to indicate their relative resistance to the other fungi.

From Tables 11 and 12 it is evident that, in 1933 and 1934, all of the wheat varieties were quite susceptible to the fungi against which they were tested. There were, however, significant variations in the susceptibility of the varieties to these fungi. The results of the root-rot garden tests of 1935 and 1936 were essentially similar to those of 1933 and 1934.

TABLE 11.—REACTION OF STANDARD VARIETIES AND NEW RUST-RESISTANT STRAINS OF WHEAT TO SOME COMMON ROOT-ROTTING FUNGI IN 1933

Variety	Station No.	Soil infested with: *Fusarium culmorum*		Miscellaneous fungi		*Helmintho-sporium sativum*		Control (natural soil)	
		D.R.[1]	Arr.[2]	D.R.	Arr.	D.R.	Arr.	D.R.	Arr.
Mindum × Pentad	533	71.6	1	69.9	2	59.5	1	60.6	5
Pentad × Marquis	1005	72.5	2	76.9	7	61.6	4	62.9	9
Double Cross	1246	73.7	3	74.6	3	63.5	8	58.3	3
H-44-24 × Reward	975	75.1	4	75.5	4	59.8	2	60.2	4
Ceres	127	76.6	5	76.5	6	67.2	11	65.6	14
Marquis	84	76.8	6	76.3	2	60.8	4	57.5	1
H-44-24 × Marquis	711	77.3	7	80.3	12	61.7	6	58.1	2
Pentad × Marquis	729	77.6	8	77.7	6	60.2	3	61.1	6
Mindum × Pentad	527	77.8	9	79.8	10	68.0	14	68.3	18
Mindum × Pentad	534	78.1	10	75.9	5	65.1	10	67.1	17
Pentad	203	78.8	11	79.3	9	64.1	9	65.9	15
Pentad × Marquis	1000	81.1	12	80.0	11	67.4	13	65.2	12
Hope × Reward	C.26.47	82.2	13	83.6	14	68.7	16	62.0	7
H-44-24 × Marquis	712	82.7	14	81.6	13	62.8	7	62.3	8
Reward	79	84.9	15	86.2	16	74.6	20	65.2	11
Pentad × Marquis	986	88.8	16	84.8	15	68.4	15	63.9	10
Mindum	568	89.6	17	87.8	17	70.8	17	65.5	13
H-44-24 × Reward	978	90.7	18	87.8	18	67.3	12	66.2	17
Reliance × Reward	1110	91.0	19	89.2	19	73.9	19	69.8	19
Pentad × Marquis	12.10.3	94.2	20	94.3	20	70.8	18	72.6	20
Standard error		±2.30		±2.30		±2.30		±2.30	

[1] D.R. = Disease rating. Each value is the mean infection rating of six plots.
[2] Arr. = Arrangement of varieties in order of resistance.

During the course of these tests, wheat varieties most resistant to *F. culmorum* were equally resistant to *H. sativum* and to the miscellaneous group of fungi, while varieties susceptible to *F. culmorum* were fairly consistently susceptible to the other root-rot fungi. In other words, there was a very significant correlation between the reactions of the wheat varieties to fungi most commonly associated with common root rot in Manitoba.

In 1934, eighteen varieties were tested against *F. culmorum* and *H. sativum* in artificially-infested plots at Winnipeg and in naturally-infested grain fields at Winnipeg and Brunkild, Manitoba. The results of these tests are given in Table 13, and provide further evidence that in any given season wheat varieties are quite stable in their reaction to *F. culmorum* and *H. sativum*, the two most common root-rotting fungi of wheat in the Prairie Provinces.

The relative susceptibility of several standard varieties and a large number of rust-resistant selections of wheat to root rot when tested in naturally and artificially-infested fields in Manitoba in 1934, 1935, and 1936 is shown in Figure 1. An examination of Figure 1 shows that, in 1934, the 5 varieties most resistant to *F. culmorum* at Winnipeg (Winnipeg A) were 3rd, 2nd, 1st, 5th and 6th in order of resistance when tested at Brunkild in field plots naturally infested with *H. sativum*. The same varieties were 9th, 1st, 7th, 6th and 8th, respectively, when grown in naturally-infested soil at Winnipeg (Winnipeg B). The behaviour of the

TABLE 12.—REACTION OF STANDARD VARIETIES AND NEW RUST-RESISTANT STRAINS OF WHEAT TO SOME COMMON ROOT-ROTTING FUNGI IN 1934

Variety	Station No.	Soil infested with: *Fusarium culmorum*		Miscellaneous fungi		*Helminthosporium sativum*		Control (natural soil)	
		D.R.*	Arr.†	D.R.	Arr.	D.R.	Arr.	D.R.	Arr.
Ceres	127	64.9	1	66.7	1	50.0	1	53.3	2
Pentad × Marquis	986	67.9	2	73.8	2	59.2	6	53.9	3
Hope × Reward	C.26.59	69.1	3	76.4	13	56.4	2	56.0	5
Reliance × Hope	1110	69.3	4	75.2	7	57.0	4	49.5	1
Pentad	203	69.8	5	76.0	10	63.5	15	57.1	7
Hope × Reward	C.26.47	69.9	6	80.1	22	64.3	19	58.3	11
Thatcher	2303	72.1	7	74.6	3	57.5	5	62.9	19
Marquis	84	72.6	8	74.6	4	60.2	7	58.8	14
Pentad × Marquis	729	72.9	9	77.1	17	61.7	10	56.6	6
Reward	79	73.0	10	75.2	8	56.7	3	58.7	12
Double Cross × Ceres	625	73.0	11	74.8	5	61.6	9	58.2	10
H-44-24 × Marquis	702	73.4	12	78.6	19	63.9	18	57.1	8
H-44-24 × Reward	967	74.3	13	76.0	11	63.7	17	58.9	15
H-44-24 × Marquis	590	74.5	14	74.9	6	67.3	23	59.6	16
Pentad × Marquis	1005	75.8	15	76.7	15	63.0	14	64.5	22
H-44-24 × Reward	978	75.9	16	79.4	20	65.5	22	57.2	9
H-44-24 × Marquis	712	76.2	17	79.7	21	64.3	20	60.2	17
Hope × Reward	C.26.123	76.6	18	75.6	9	62.9	13	54.9	4
Hope × Reward	1134	76.6	19	76.1	12	60.9	8	58.7	13
H-44-24 × Marquis	711	76.7	20	77.0	16	64.9	21	61.5	18
Pentad × Marquis	12.10.3	77.0	21	80.2	23	62.1	12	63.2	20
H-44-24 × Reward	975	77.6	22	76.5	14	61.8	11	64.7	23
H-44-24 × Reward	716	77.6	23	80.5	24	67.6	24	65.0	24
Mindum	568	80.1	24	77.3	18	63.5	16	64.1	21
Standard error		±2.25		±2.25		±2.25		±2.25	

* D.R. = Disease rating. Each value represents the mean infection rating of six plots.
† Arr. = Arrangement of varieties in order of resistance.

28 wheat varieties was quite consistent when tested at 3 different stations in 1935, that is, the group of varieties with most resistance at one station was composed of the varieties showing the most resistance at the other stations, and varieties most susceptible at one station were most susceptible at the other stations. Results essentially similar to those of 1934 and 1935 were obtained in 1936.

In general, the results show that each year during the course of the investigation some of the standard varieties and new rust-resistant selections of wheat were fairly consistently resistant to *Fusarium-Helminthosporium* root rot, while other varieties and selections were consistently susceptible. Wheat varieties resistant when *F. culmorum* was the predominating pathogenic fungus in the soil were most resistant when *H. sativum* was the most common root-rotting fungus present, while susceptibility to one of these organisms was significantly associated with susceptibility to the other.

From Figure 1 it is evident that wheat varieties vary considerably in their susceptibility to *Fusarium-Helminthosporium* root rot. In 1935, for example, the disease-infection rating of individual varieties in the Winnipeg test varied from 69 to 96. Statistically significant variations in the sus-

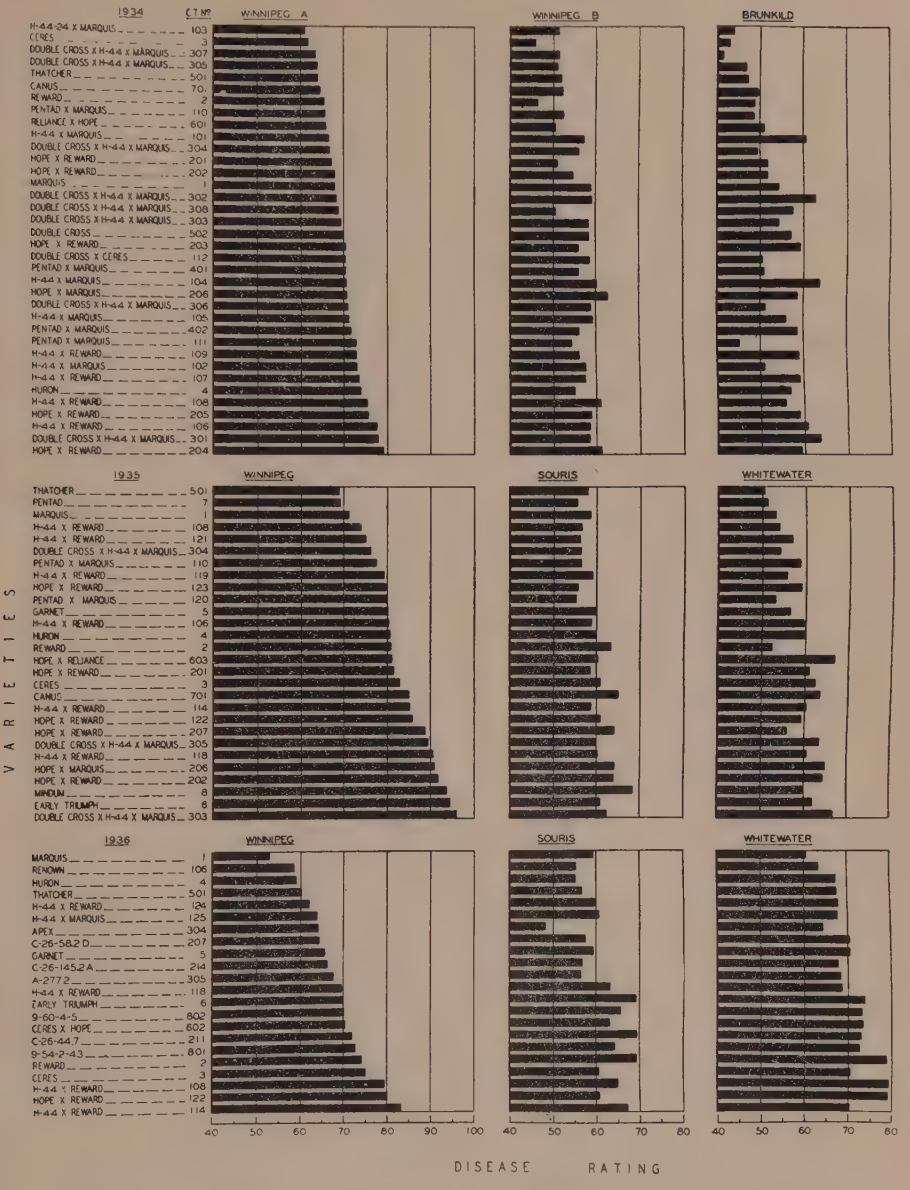

FIGURE 1. Reaction of varieties and rust-resistant selections of wheat to root rot caused by *Fusarium culmorum* and *Helminthosporium sativum*. Results of field tests made in Manitoba in 1934, 1935, and 1936. The Winnipeg tests,—*Winnipeg A* and *Winnipeg*—were made in soil infested artificially with *F. culmorum*. In *Winnipeg B* test of 1934 the soil was infested naturally with *F. culmorum* and other fungi. The Brunkild field was naturally infested with *H. sativum*. Tests at Souris and Whitewater were made in soil naturally infested with *F. culmorum* and other fungi.

ceptibility of wheat varieties to root rot were observed in all tests made during the 3-year period 1934–36.

The results of observations and experiments over a period of years have indicated that environmental factors, age of the plant, as well

TABLE 13.—REACTION OF WHEAT VARIETIES TO ROOT ROT CAUSED BY *Fusarium culmorum* AND *Helminthosporium sativum* UNDER NATURAL AND ARTIFICIAL ATTACKS OF THESE FUNGI IN MANITOBA IN 1934

Variety	Station No.	Disease rating*							
		Kind of soil infestation							
		Fusarium culmorum				*Helminthosporium sativum*			
		Artificial	Natural	Mean	Arr.†	Artificial	Natural	Mean	Arr.†
Ceres	127	64.9	53.3	59.1	1	50.0	43.0	46.5	1
Reliance × Hope	1110	69.3	49.5	59.4	2	56.9	51.0	53.9	4
Pentad × Marquis	729	62.9	56.6	59.8	3	61.7	58.4	60.0	13
Pentad × Marquis	986	67.9	53.9	60.9	4	59.2	45.5	52.3	3
Hope × Reward	C.26.59	69.1	56.0	62.5	5	56.4	51.9	54.1	5
Hope × Reward	C.26.47	69.9	58.3	64.1	6	64.3	58.7	61.5	15
H-44-24 × Marquis	702	73.4	57.1	65.2	7	63.9	51.2	57.5	12
Double Cross × Ceres	625	73.0	58.3	65.6	8	61.6	50.6	56.1	7
Marquis	84	72.6	58.8	65.7	9	60.1	54.8	57.4	10
Reward	79	73.0	58.7	65.8	10	56.7	51.9	54.3	6
H-44-24 × Reward	978	75.9	57.2	66.5	11	65.5	58.7	62.1	16
Thatcher	2303	72.1	62.9	67.5	12	57.5	46.6	52.0	2
Hope × Reward	1134	76.6	58.7	67.6	13	62.9	52.0	57.4	11
H-44-24 × Marquis	712	76.2	60.2	68.2	14	64.3	56.0	60.1	14
H-44-24 × Marquis	711	76.7	61.5	69.1	15	64.9	63.8	64.3	17
Pentad × Marquis	12.10.3	77.0	63.2	70.1	16	62.1	50.9	56.5	8
H-44-24 × Reward	975	77.6	65.7	71.6	17	61.8	52.5	57.1	9
H-44-24 × Reward	716	78.6	69.0	73.8	18	68.6	60.3	64.4	18
Standard error		±2.25	±2.25	±1.59		±2.25	±3.50	±2.46	

* Each value represents the mean infection rating of six plots.
† Arr. = Arrangement of varieties in order of resistance.

as varietal difference, play a very important part in determining the occurrence and severity of root-rot attacks on wheat. Furthermore, it is recognized that, owing to the interaction of these and other factors, considerable variation in the severity of root-rot infection on individual varieties occurs from season to season. It is well, therefore, in determining the susceptibility of a variety to root rot, to consider the behaviour of the variety over a series of years.

From this point of view it is interesting to compare the susceptibility to root rot of three new rust-resistant varieties of wheat, Thatcher, Apex, and Renown, with that of three standard and commonly-grown varieties, Marquis, Reward, and Garnet. The results of tests made with these varieties during the 3-year period 1934–36 are summarized in Table 14.

It is evident from Table 14 that, in the process of breeding and selecting varieties resistant to rust, some progress has been made in securing strains of wheat resistant to root rot. This result might be expected, for, in the process of breeding for rust-resistance, only wheat strains of high yielding ability and of good grain quality were finally selected and increased for commercial distribution. The results in Table 14 show that Apex and Thatcher were, during the three years 1934–36, slightly more resistant to root rot than were the standard varieties Marquis, Reward and Garnet.

TABLE 14.—SUSCEPTIBILITY OF SOME STANDARD AND RUST-RESISTANT VARIETIES OF SPRING WHEAT TO *Fusarium-Helminthosporium* ROOT ROT, 1934–36

Variety	Disease rating*						
	Root-rot garden studies†		Varietal tests‡			Mean of tests 1934–36	General mean
	1934	1935	1934	1935	1936		
Marquis	66.6	71.6	60.5	61.2	59.7	63.9	
Reward	65.9	71.7	53.6	61.8	73.3	65.3	66.9
Garnet	—	72.8	—	68.3	73.5	71.5	
Apex	—	69.1	57.6	62.0	57.1	61.4	
Thatcher	66.8	66.8	54.3	58.5	63.7	62.0	62.7
Renown	72.2	65.6	66.4	63.2	56.6	64.8	

* Disease rating computed on basis of number of seeds sown; highest numerical rating for non-emergence.
† Each value represents the mean of four tests (24 plots).
‡ Co-operative tests of new wheat varieties conducted by the Sub-committee on Plant Breeding, Associate Committee on Field Crop Diseases (Western Section), National Research Council and Dominion Department of Agriculture, Ottawa. Each value represents the mean of replicated tests at three stations in 1934, and at four stations in 1935 and 1936.

On the other hand, Renown was considerably more resistant than Garnet, but it did not differ significantly from Marquis and Reward in its reaction to root rot.

Germination and Plant Emergence.

The germination capacity, or rather the ability of the grain to produce young plants, has been generally considered an important index of the resistance of wheat varieties to common root rot, particularly the seedling-blight phase of this disease. In the variety tests made in Manitoba in 1934, 1935, and 1936, the number of plants that emerged in the 100-seed rows of each variety plot was counted about 4 weeks after planting. The results of counts made in various artificially and naturally-infested soils are summarised in Table 15.

The results in Table 15 show that there is a significant variation in the ability of wheat varieties to germinate and produce young plants. The average results with 36 varieties in 1934 (1,200 seeds of each) show that the range in plant emergence of individual varieties was from 36 to 64%. In 1935 the range in plant emergence of 28 varieties (1,200 seeds of each) was from 53 to 74%. The varietal range in percentage of plants emerged, based on the average count of four tests in 1936 with 22 varieties (2,000 seeds of each), was from 42 to 67, or a difference of 25%. The ability of the seed of some wheat varieties, especially the new rust-resistant varieties Apex and Thatcher, to germinate and produce young plants was uniformly high in all years and in all tests, while the seed of some of the varieties gave consistently low figures for the number of emerged plants.

The results of the Winnipeg tests on artificially and naturally-infested soil show that, during the three years 1934–36, artificial infestation of the seed and of the soil with *F. culmorum* markedly reduced plant emergence. In 1935, the average difference in number of plants emerged of 28 varieties between artificially and naturally-infested plots was 37.1%.

From Table 15 it is evident that, under Manitoba conditions, wheat varieties vary considerably in their ability to germinate and produce young plants. In the case of several of the varieties tested, the percentage of plant emergence was very low. This suggests that, in any wheat improvement programme, the problem of breeding to increase the ability of

TABLE 15.—THE ABILITY OF WHEAT VARIETIES TO GERMINATE AND PRODUCE YOUNG PLANTS IN FIELD PLOTS NATURALLY AND ARTIFICIALLY INFESTED WITH *Fusarium culmorum*. SUMMARY OF RESULTS IN 1934, 1935, AND 1936

Year	Station	Number of varieties*	Kind of soil infestation	Percentage of plants emerged (after 35 days)†	
				Range within varieties	Average of all varieties
1934	Winnipeg	36	Artificial	17–46	32.7
	Winnipeg	36	Natural	21–69	54.1
	Brunkild	36	Natural‡	44–77	59.4
	Mean of 3 tests			36–64	48.7
1935	Winnipeg	28	Artificial	9–54	32.4
	Winnipeg	28	Natural	58–82	69.5
	Souris	28	Natural	82–95	89.8
	Whitewater	28	Natural	26–75	63.5
	Mean of 4 tests			53–74	63.8
1936	Winnipeg	22	Artificial	32–74	52.0
	Winnipeg	22	Natural	44–79	66.5
	Souris	22	Natural	41–80	62.1
	Whitewater	22	Natural	36–58	47.0
	Mean of 4 tests			42–67	56.9

* Standard varieties and new rust-resistant strains of wheat selected by the Subcommittee on Plant Breeding, Associate Committee on Field Crop Diseases.

† Results based on the mean of four plots (400 seeds) of each variety, except in tests at Souris and Whitewater in 1936 when the results represent the mean of six plots (600 seeds) of each variety.

‡ Varieties grown at Brunkild in soil naturally infested with *Helminthosporium sativum*.

the grain to produce strong young plants, is one deserving particular attention. Further studies to determine the effect of this character on the resistance of cereal varieties to common root rot are required. The importance of breeding spring wheats to raise the germinability of the grain has been recently emphasized by Navolotskiĭ and Navoltskaja (5).

Behaviour of Oat Varieties

Tests to determine the relative susceptibility of oat varieties to root rot caused by *Fusarium culmorum* were begun at Winnipeg in 1934. In that year 10 varieties, including new rust-resistant strains and standard varieties, were grown in plots artificially infested in one-half with *F. culmorum*. This test was repeated in 1935 and 1936. The technique of soil infestation, the arrangement of plots, and the methods of recording and analysing experimental data employed in the oat tests were similar to those used in the Winnipeg root-rot tests with wheat, and have already been

described. All varieties and strains used were secured from the Cereal Division, Dominion Rust Research Laboratory, Winnipeg, Man. Separate data of each test were subjected to statistical treatment. Table 16 gives the complete analyses of variance for plant emergence and disease rating of these experiments.

TABLE 16.—ANALYSES OF VARIANCE FOR PERCENTAGE OF PLANTS EMERGED AND DISEASE RATING IN OATS. VARIETAL TESTS, WINNIPEG, 1934–36

Variance due to	Degrees of freedom	Sum of squares	Mean square	F	1% point
	Percentage of plants emerged				
Replicates	11	5,717.73	519.79		
Years	2	2,679.69	1,339.84	18.76	4.82
Varieties	9	4,210.32	467.81	6.55	2.69
Varieties × years	18	6,377.66	354.31	4.96	2.37
Error (a)	99	7,069.67	71.41		
Total	139	26,055.07			
Treatments (soil)	1	35,100.80	35,100.80	567.79	6.84
Treatments × varieties	9	3,284.52	364.94	5.90	2.66
Treatments × years	2	8,391.02	4,195.51	57.86	4.78
Treatments × varieties × years	18	2,640.91	146.71	2.37	2.33
Error (b)	110	6,800.25	61.82		
Total	140	56,217.50			
	Disease rating				
Replicates	11	2,960.48	269.13		
Years	2	62,102.80	31,051.40	533.52	4.82
Varieties	9	2,524.36	280.48	4.82	2.69
Varieties × years	18	3,675.94	204.22	3.50	2.37
Error (a)	99	5,761.31	58.20		
Total	139	77,024.89			
Treatments (soil)	1	20,960.68	20,960.68	610.92	6.84
Treatments × varieties	9	1,818.92	202.10	5.89	2.66
Treatments × years	2	7,409.13	3,704.56	107.97	4.78
Treatments × varieties × years	18	1,444.40	80.24	2.33	2.33
Error (b)	110	3,774.45	34.31		
Total	140	35,407.58			

The analyses in Table 16 establish significant differences, both with respect to plant emergence and disease rating, between artificially and naturally-infested soil. In both cases the variance for soil treatments is much greater than the error variance. Thus the results indicate that a high degree of significance can be attached to the method of inducing positive root-rot attacks on oats by adding inoculum of *F. culmorum* to the seed and soil. The mean varietal results of 1934, 1935, and 1936, showing the effect of artificial and natural infestation of the soil on number of plants emerged, degree of root-rot infection, and yield, are summarised in Table 17.

From Table 17 it is evident that positive attacks of root rot of oats were produced by artificial infestation of the plots with *F. culmorum*. The effectiveness of the method used to infest field plots is established with a high degree of probability. The mean differences in number of plants emerged, disease rating, and yield between artificially and naturally-

TABLE 17.—EFFECT OF ARTIFICIAL INFESTATION OF THE SOIL WITH *Fusarium culmorum* ON PLANT EMERGENCE, INCIDENCE OF ROOT ROT, AND YIELD IN OATS. VARIETAL TESTS, WINNIPEG, 1934–36

Soil treatment	1934	1935	1936
	Percentage of plants emerged*		
Artificially infested with *F. culmorum*	37.2	45.9	57.2
Control (natural soil)	72.6	72.8	67.6
Decrease due to *F. culmorum*	35.4	26.9	10.4
Standard error	±1.45	±0.96	±1.10
	Disease rating*		
Artificially infested with *F. culmorum*	60.3	71.3	61.9
Control (natural soil)	28.3	53.4	54.8
Increase due to *F. culmorum*	32.0	17.9	7.1
Standard error	±1.04	±0.80	±0.75
	Yield (bus. per acre)*		
Artificially infested with *F. culmorum*	51.5	25.0	52.9
Control (natural soil)	78.7	32.8	55.4
Decrease due to *F. culmorum*	27.2	7.8	2.5
Standard error	±1.63	±1.23	±0.69

* Each value represents the general mean of 10 varieties. There were 40 plots of each soil treatment in 1934 and 1935, and 60 plots of each in 1936

infested plots were very great in 1934. These results with oats confirm those of the wheat-varietal tests and show that plant emergence was reduced, disease infection increased, and yield decreased when the soil was artificially infested with *F. culmorum*.

The magnitude of the mean squares for varieties in relation to the mean squares for error (Table 16), indicates that the oat varieties tested are not genetically similar in their reaction to root-rot caused by *F. culmorum*. The differences observed in the susceptibility of these varieties, based on the varietal means for 1934, 1935, and 1936, are shown in Table 18.

It will be noted in Table 18 that the varieties Victoria and Ohio, and the rust-resistant selection Hajira × Banner (S.13) were most resistant to root rot, while the standard varieties Banner and Victory were most susceptible. It is evident from the results that oat varieties vary considerably in their reaction to root rot.

TABLE 18.—SUSCEPTIBILITY OF STANDARD AND RUST-RESISTANT VARIETIES OF OATS TO ROOT-ROT. AVERAGE RESULTS OF TESTS MADE IN NATURAL SOIL AND IN SOIL ARTIFICIALLY INFESTED WITH *Fusarium culmorum* IN 1934, 1935, AND 1936

Variety	Station No.	Percentage of plants emerged*			Disease rating*		
		Kind of soil infestation					
		Natural	Artificial	Mean	Natural	Artificial	Mean
Victoria	1006	76.8	56.8	66.8	30.0	46.3	38.2
Ohio	105	68.8	60.8	64.8	36.1	42.1	39.1
Hajira × Banner	S.13	74.5	49.1	61.8	34.4	52.9	43.7
Joanette	561	69.0	46.4	57.7	34.1	53.4	43.8
White Russian	177	71.1	46.4	58.8	34.5	54.4	44.4
Hajira × Banner	S.553	71.8	49.6	60.7	36.6	52.1	44.4
Hajira	559	64.1	50.1	57.1	40.2	51.9	46.1
Hajira × Banner	S.339	69.5	44.2	56.8	36.6	56.7	46.7
Victory	159	72.1	38.2	55.2	33.8	59.6	46.7
Banner	179	68.2	40.3	54.2	37.8	57.4	47.6
Mean of soil treatments†		70.6	48.2	59.4	35.4	52.7	44.1
Standard error of varieties		±2.26	±2.26	±1.60	±2.01	±2.01	±1.44

* Each value is the mean of replicated tests of 1934, 1935 and 1936. Varieties arranged in order of resistance according to disease rating.

†Standard error of mean of soil treatments: Percentage of plants emerged = ±0.66; Disease rating = ±0.49.

An examination of the analyses in Table 16 shows that the number of plants emerged and the degree of root-rot infection on oat varieties varied from year to year. This is established by the significant mean squares for years as compared with those for error. These results suggest that environmental factors, affecting as they do the growth of the pathogen as well as that of the plant, cause rather wide fluctuations in the severity of root-rot infection on individual oat varieties from season to season. From Table 16 it will be further observed that the interaction of varieties and years, both for plant emergence and disease rating, is quite significant. Thus further evidence is produced to show the importance of testing the reactions of oat varieties to root rot over a period of years rather than in a single season. These results with oats are essentially similar to those obtained in tests to determine the susceptibility of varieties of wheat to root rot.

The mean squares obtained for the interaction of soil treatments and years compared with those obtained for error are very significant (Table 16). This establishes that the effect of soil infestation with *F. culmorum* varied in different years. From the results in Table 17 it would appear that the seasonal conditions of 1934 were more favourable for the development of *F. culmorum* on oats than were those of 1935 and 1936.

The increase in root rot that may be expected due to artificial infestation of the soil with *F. culmorum* is dependent, to some extent at least, on the varieties used. This is demonstrated, both in respect to plant emergence and disease rating, by the significant mean squares obtained for the interaction of soil treatments and varieties (Table 16). That is, the varietal differences were not the same under the two conditions of plot treatment,

namely, artificial and natural infestation. Hence it would appear that the differential effect of artificial infestation of the soil on resistant and susceptible varieties was not consistent for the three years of the test. The nature of the conditions that bring about these differential responses is not at present clear.

SUMMARY

During the 7-year period 1930–36, several standard varieties and a large number of rust-resistant selections of spring wheat were tested for resistance to root-rot caused by *Fusarium culmorum* and *Helminthosporium sativum*. In 1934, 1935, and 1936 field studies were made to determine the relative susceptibility of ten standard varieties and rust-resistant strains of oats to root-rot caused by *Fusarium culmorum*.

A statistical study of the disease and yield data of several experiments indicated that the disease-rating method of recording the intensity of root-rot caused by *F. culmorum* and *H. sativum* in wheat gives a reliable index of the amount of injury caused by this disease in the field. The results established that the disease rating was significantly negatively associated with yield. It was therefore considered that this method of recording disease intensity was sufficiently accurate to be used as an indication of the reaction of varieties and selections of wheat and of oats to root-rot under field conditions.

Positive attacks of root-rot of wheat and of oats were obtained each year when *F. culmorum* was introduced into the soil. The methods used to establish successful epidemics with this fungus in field plots are described in detail.

Tests made each year during the 3-year period 1934–36, with a large number of wheat varieties, indicated that germinability, or rather the ability of the grain of wheat varieties to produce young plants, varied greatly under field conditions in Manitoba. Germinability was shown to be highest in the varieties and selections that were most resistant to root-rot, and lowest in the most susceptible ones. This result emphasized the importance of this character in the improvement of wheat varieties.

All the standard varieties as well as most of the rust-resistant selections of wheat tested in the course of the investigation, proved to be quite markedly susceptible to *Fusarium-Helminthosporium* root rot. In any given year there were, however, significant differences between varieties of wheat in their reaction to this disease.

The variety Mindum and a few selections with Mindum parentage were most susceptible to root-rot, while a few of the new rust-resistant selections, particularly Apex and Thatcher, proved to be the most resistant. From the results of extensive varietal tests made during the 3-year period 1934–36, it would appear that, in the process of breeding and selecting for rust-resistance in wheat, some slight progress has been made in securing resistance to root rot.

In general, the results established that, in any given year, wheat varieties susceptible to root rot caused by *F. culmorum* were, even when grown under a wide range of field conditions, consistently susceptible to this fungus; while the most resistant varieties were consistently the most

resistant. Moreover, it was found that wheat varieties most resistant to *F. culmorum* were fairly consistently resistant to *H. sativum*, while susceptibility to one of these fungi was significantly associated with susceptibility to the other.

Tests made in 1934, 1935, and 1936 demonstrated that there is a significant variation in the reaction of oat varieties to root-rot caused by *F. culmorum*. The varieties Ohio and Victoria and the rust-resistant hybrid Hajira × Banner (Selection 13) were most resistant, while the standard varieties Victory and Banner were, of the ten varieties and selections tested, most susceptible.

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CONTROL OF SNAPDRAGON RUST (*PUCCINIA ANTIRRHINI* D. & W.)

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Copper-containing sprays proved more satisfactory than sulphur treatments as preventatives of snapdragon rust on Vancouver Island. This supports the recent investigation of Green (2) in England, but is contrary to the common belief that sulphur compounds are superior to copper as rust preventives and to the recommendations for snapdragon rust control of Butler (1), White (4), Tilford (5), Neis (3), and others.

Rust has reduced seed yield and lowered the ornamental value of snapdragons in the coastal area of British Columbia for many years. Complete failures have been reported by some of the seed growers.

This paper gives the relative value of different copper and sulphur sprays as preventives of snapdragon rust at Victoria, British Columbia.

MATERIALS AND METHODS

Spray materials used in this snapdragon rust experiment are listed in Tables 1 and 2. The rust appeared too late in 1934 and 1935 to justify taking the data. In 1936 the plots were sprayed on July 7 and 17 and in 1937 on June 30 and July 22. Great care was taken to get a coverage of the spray on the underside of the leaves as well as on top. The approximate quantity of spray required for one acre was 160 gallons, which made the cost of the spray material, Bordeaux 4–4–40 plus agral 2, less than $2.50 per acre for each application. Two men with barrel pump sprayed an acre in two days.

Each plot, which was replicated, consisted of 5 rows, 18 inches apart by 12 feet, and contained 60 plants.

The amount of copper was approximately the same in the following sprays applied in 1937: Bordeaux, Burgundy, Bouisol, Copper hydro and Micronised Burgundy.

Volunteer and other snapdragon plants have been destroyed before spring since 1933 on the seed farm where the investigation was conducted.

The data were taken on September 23 and 14, 1936 and 1937 respectively.

RESULTS

Bordeaux 4–4–40 plus a spreader like agral 2, applied to give coverage on the underside of the leaves, as well as on top, was an effective preventive of snapdragon rust (Table 1 and 2) and Plate 1. Only two applications of Bordeaux plus a spreader were necessary in 1936 and 1937 to protect the seed crop. The Bordeaux mixture used in these experiments was different from that used by Green (2) in that quicklime was used instead of hydrated lime and the strength was increased from 4–5–50 to 4–4–40. Green found Burgundy the best in England, while Bordeaux appears definitely superior at the Coastal areas of British Columbia. Although

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PLATE I

PLATE I. Snapdragon foliage. 1. Sprayed twice with bordeaux 4-4-40. 2. Sprayed twice with lime-sulphur 1-50. 3. Sprayed twice with bordeaux 4-4-40 plus a spreader. 4. Unsprayed.

TABLE 1.—THE EFFECT OF DIFFERENT SPRAYS ON THE AMOUNT OF SNAPDRAGON RUST IN 1936

Treatment*	Amount of leaf area rusted
	%
Check	62.5
K.S. Resin 1 lb. to 10 gals.	49.6
Lime sulphur 1–50 plus penetrol	45.7
Lime sulphur 1–50 plus lethelate	65.0
Bordeaux 4–4–40	13.4
Bordeaux plus penetrol	0.7
Bordeaux plus lethelate	0.8
Bouisol 2 pints per 100 gals. plus penetrol	23.4

* Spreaders were used at the following strength per 100 gals. of spray: Agral 2—1 lb.; Lethelate—1 pint; Penetrol—2 quarts.

TABLE 2.—THE EFFECT OF DIFFERENT SPRAYS ON THE AMOUNT OF SNAPDRAGON RUST IN 1937

Treatment*	Amount of leaf area rusted
	%
Check	71.8
Lime Sulphur 1–50 plus agral 2	30.5
Bordeaux 4–4–40	10.5
Bordeaux 4–4–40 plus agral 2	2.1
Bordinette 1 lb. to 10 gals. plus agral 2	12.2
Bouisol 1 and $\frac{2}{3}$ lbs. to 10 gals. plus agral 2	7.8
Burgundy 4–5–40 plus agral 2	14.5
Copper hydro 1 lb. to 10 gals. plus agral 2	12.2
Micronised Burgundy $1\frac{1}{4}$ lbs. to 10 gals plus agral 2	23.6

* Spreaders were used at the following strength per 100 gals. of spray: Agral 2—1 lb.

Bordeaux with a spreader was more effective than other copper sprays for the control of snapdragon rust, it discolours the foliage and hence cannot be recommended when snapdragons are grown for ornamental purposes. Consequently, we agree with Green that copper sprays are more effective than sulphur sprays.

The following copper sprays with a spreader gave sufficient protection from rust on snapdragons grown for seed to warrant trial on ornamental snapdragons: Bouisol 1 pint to 10 gallons of water; Bordinette 1 pound per 10 gallons; Burgundy 4–5–40; and Copper hydro 1 pound to 10 gallons. By increasing the strength of Bouisol from 1 pint to 50 gallons of water in 1936 to 1 pint to 10 gallons in 1937, the effectiveness of the spray was improved.

Spraying after the flowers begin to open was not necessary to protect snapdragons grown for seed. The increase in number and growth of leaves was small after flowering began. Further evidence of the effectiveness of Bordeaux 4–4–40 plus agral 2 is indicated from the results obtained by a seed grower who sprayed 25,000 plants twice in July and left 120 plants

unsprayed. The sprayed plants gave a normal crop of seed, while the unsprayed were nearly a complete failure.

Spreaders agral 2, Lethelate and Penetrol increased the efficacy of Bordeaux.

Burning of volunteer and other snapdragon plants before spring since 1933 may account for the late appearance of rust in 1934, 1935, 1936 and 1937. The earliest date that rust was observed in 1934, 1935, 1936 and 1937 was on July 29, 1937. Previously rust was commonly observed in June and sometimes in May.

SUMMARY

1. Copper sprays are more effective than sulphur in the control of snapdragon rust in the coastal areas of British Columbia.

2. Bordeaux 4–4–40 plus a spreader, agral 2, lethelate, or penetrol, is an effective preventive of rust in snapdragons grown for seed.

3. Only two applications of Bordeaux plus a spreader were necessary in 1936 and 1937 to protect the seed crop.

4. Spraying after the flowers begin to open is not necessary in the case of plants grown for seed.

5. Spreaders agral 2, lethelate and penetrol improve the efficacy of Bordeaux.

6. The following copper sprays plus agral 2 gave sufficient protection from rust on snapdragons grown for seed to warrant their trial on ornamental snapdragons: Bouisol 1 pint to 10 gals. of water, Bordinette 1 lb. to 10 gals. of water, Copper hydro 1 lb. to 10 gals of water and Burgundy 4–5–40.

7. Burning of volunteer and other snapdragon plants before spring since 1933 may account for the late appearance of rust in 1934 to 1937, inclusive.

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OAT NEMATODES ON WINTER WHEAT

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During the summer seasons of 1933–34, when the previously reported investigations (2) on the disease of cereals caused by the oat nematode *Heterodera schachtii* Schm. were being conducted in South Simcoe county, it was found that winter wheat was also a host of this parasite. It was observed at that time that the nematodes did attack winter wheat, and that they could complete their life cycle in the wheat roots; but no cases of severe damage to the wheat crop, traceable to nematode infestation, were encountered in the course of a detailed survey of the grain fields of the district. However, in the spring of 1937, our attention was drawn to three fields of winter wheat in the infested area which were obviously unhealthy, and they were kept under observation during the season. One of these fields was plowed up as a crop failure, while the diseased portions (about 75%) of the other two fields, were not worth cutting. Detailed examination established the fact that the roots of the plants in these areas were more heavily infested with nematodes than any winter wheat roots previous observed. It is the purpose of this communication, therefore, to record these instances of crop failure and to provide a brief description of the effects of this disease upon winter wheat.

The upper parts of the infested plants are stunted, and support very small, poorly-filled heads. The root systems show the characteristic bushy appearance and local thickening previously described in detail for oats (2). A comparison of diseased and healthy root systems of winter wheat of the variety Dawson's Golden Chaff is seen in Figure 1. It is notable that wheat roots, even more than oat roots, exhibit the local swellings from which emanate bunches of rootlets as depicted in Figure 2. When maturing, the female nematodes may readily be seen with the naked eye, as they appear on the outside of the roots.

It must not be concluded, however, that all fields of winter wheat, sown on sites that are heavily infested with oat nematodes, will result in crop failure. Cases to the contrary are easily found, and it is not clear why these particular fields were so badly damaged. Since the crop was not seen in the early stages, it is impossible to state whether the injury occurred in the spring or in the previous fall, but it is worth mentioning that all three fields were sown unusually early, having been seeded August 28 to September 1. The early seeding would permit a maximum of infestation to take place in the early autumn and this may, in part, account for the extraordinary amount of damage experienced. The intervening winter was also very mild, hence it may have been a more complex set of conditions which combined to favour the progress of the nematodes. Finally, there is the possibility of the development of a physiological race which is adapted to winter wheat. Goodey (1), in reviewing the question of biologic races,

[1] Research Fellow.

cites evidence to show that the oat race of *H. schachtii* Schm. is not homogeneous, and that further segregation may take place. Further study is therefore required before any more definite interpretation can be advanced concerning the causes of the outbreak.

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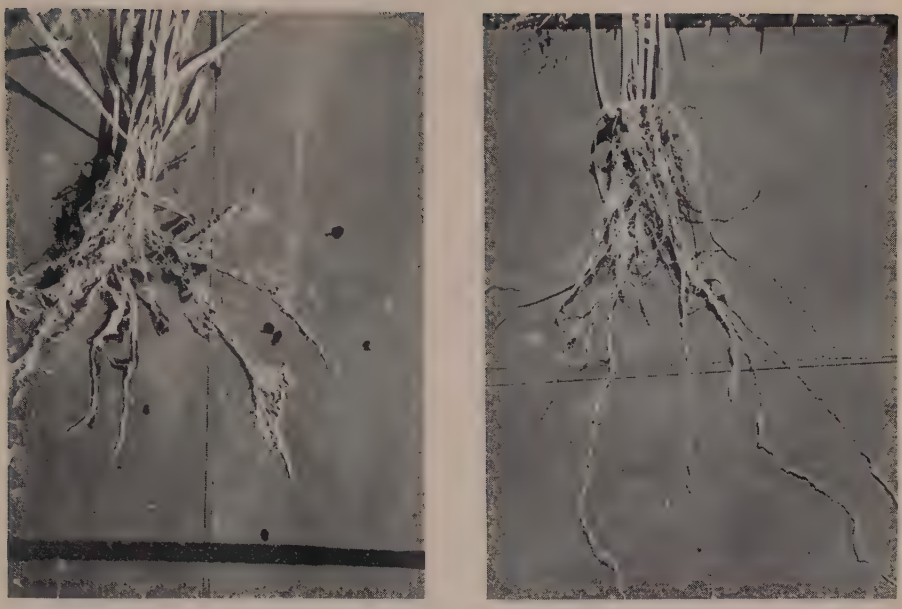

FIGURE 1. A comparison of diseased (left) and healthy (right) root systems of winter wheat.

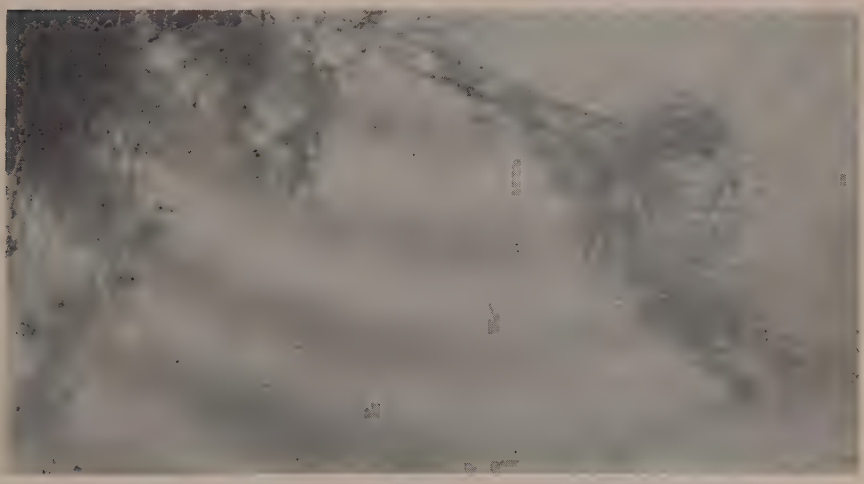

FIGURE 2. Roots of winter wheat, infested with nematodes.

THE CONTROL OF THE GREENHOUSE WHITEFLY IN CANADA BY THE PARASITE *ENCARSIA FORMOSA* GAHAN

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INTRODUCTION

The greenhouse whitefly *Trialeurodes vaporariorum* Westw. is one of the most common pests of greenhouse crops. Satisfactory artificial control is difficult, due to the inability of most poison sprays, dusts, or fumigants to kill all stages of the insect. The results of investigations and observations at the Dominion Parasite Laboratory during the past 9 years have shown that the greenhouse whitefly can be controlled by the parasite *Encarsia formosa* Gahan. The investigations have also shown that the control of greenhouse insects by parasites is a specialized field of biological control. Many factors that complicate the attempted control of insects in the field, such as temperature, humidity and rate of dispersal, can be controlled under greenhouse conditions. One factor, however, that is not usually important in the field is of extreme importance when attempting to control greenhouse insects by biological methods. That is, the fact that frequently an insect pest must be controlled before the crop on which it is feeding is marketed, whereas in the field the time factor is not so important. To be successful under greenhouse conditions, a parasite must have the ability to increase rapidly and to control its host quickly. Even the most prolific parasite cannot be expected to control in a few weeks a pest that is present in large numbers. For this reason, the control of greenhouse insects by parasites is dependent upon the introduction of the parasites before a heavy infestation of the pest has developed, or where, as is the case with *Encarsia formosa*, the parasites can be used in conjunction with artificial control methods.

HISTORY OF THE PARASITE

The country of origin of *Encarsia formosa* is not known, but since it cannot survive extremes of either heat or cold it is probably of semitropical origin.

This chalcid parasite of the family Aphelinidae was first recorded in 1924, when specimens taken in the United States from Ohio were described by Gahan. Two years later (1926) it was found in a small greenhouse in England. Parasitized scales were sent to the Cheshunt Experiment Station where the life-history and habits were studied, and where technique for distribution under English conditions was developed by Speyer (1, 2). The desirability of obtaining the parasite from England was discussed in 1928 with Sir Guy Marchall, Director of the Imperial Institute of Entomology, by Dr. Arthur Gibson, Dominion Entomologist. Soon afterwards, Dr. W. R. Thompson, in that year appointed as Superintendent of

[1] Graduate Assistant.

the Farnham House Laboratory, obtained from Mr. E. R. Speyer, a supply of the parasite, which was forwarded to Canada. Distribution has also been made through Farnham House Laboratory to other parts of the British Empire. Following the receipt of the parasites in Canada, a survey made by Mr. A. B. Baird showed that the species was already present in a number of greenhouses. Establishment of the parasite in the Channel Islands was secured in 1928. Several unsuccessful attempts were made to secure its establishment in Australia and New Zealand. However, in 1934, Muggeridge (3) reported the establishment and distribution of the parasite in New Zealand. In 1936 it was introduced into Australia from New Zealand. Finally Tannoir (4) reported its establishment in Tasmania. A species of *Encarsia*, probably *formosa*, was reported by Weber (5) attacking *Trialeurodes vaporariorum* in Germany.

The rapid establishment and distribution of this parasite are largely due to the fact that it reproduces parthenogenetically. Although a small percentage of males are produced, they are not necessary for reproduction and appear to be impotent. This method of reproduction, and the fact that there have been no secondary parasites recorded in Canada, gives the parasite a decided advantage over the host insect, and increases its effectiveness. Its effectiveness is recognized by commercial greenhouse men, many of whom have expressed the opinion that it provides an excellent means of supplementing and, under certain conditions, substituting for artificial methods of control. Some of the weak points in artificial control of the pest are listed below:

1. Cyanide, which may be cited as representative of the "gas" method of control, is effective, if properly used, in killing the adults of the pest but usually does not kill more than 80% of the immature stages.
2. Greenhouses that are not reasonably airtight are unsuitable for fumigation, due to air movement which causes unequal distribution of the gas, and results in an unsatisfactory kill in some sections and a possibility of burning of the plants in others.
3. Many greenhouse men produce several varieties of plants in the same house and often one or more varieties are susceptible to gas injury and, therefore, cannot be fumigated.
4. Fumigation is unsafe in any greenhouse or conservatory which is attached to a dwelling.
5. Many large ranges of greenhouses cannot be divided easily; for this reason it is difficult to control by fumigation an infestation in one or two small areas.
6. The personal factor is important. Many operators use too strong or too weak a concentration of gas, and either the plants are injured or an unsatisfactory kill results.
7. If an insecticide in the form of a spray or dust is used, the immature stages of the whitefly can be killed if all leaf surface is completely covered. This is very difficult to do with many varieties of plants such as primulas. Even with complete leaf coverage many adults escape and continue the infestation.

PRODUCTION

Summer Rearing

It has been found that after rearing from 7 to 9 generations of the host and parasite in a greenhouse through the autumn, winter, and spring months, more satisfactory results the following year can be expected if a few generations are reared out of doors during the summer. Colonies of both host and parasite are transferred from the greenhouse to the garden in June. If proper conditions and suitable host plants are provided, the insects propagate and increase with very little attention. In autumn, the exact time being dependent upon weather conditions, young tomato plants growing in cold frames are artificially infested with adult whiteflies. After about two weeks, the parasites are introduced. When there is a possibility of frost the infested plants are moved into the greenhouse. In this way a vigorous supply of host plants, host insects and parasites is provided for winter propagation each year.

During the summer, shade, other than that provided by the host plant, is necessary at extremely high temperatures, particularly if the humidity and soil moisture is low. Unsuitable conditions are indicated by the wilting of the host plants. The effect is probably secondary. Transpiration is greatly reduced when wilting occurs, which results in an increase in the temperature of the leaf surface and a decrease in the relative humidity to a point that is lethal to the larval and pupal stages of the host insect. This condition can be prevented by planting the host plants under trees or in the shade of buildings.

The following host plants, listed in order of suitability, have been used for summer propagation: tobacco, (cigar leaf type), tomato, squash, morning glory, hollyhock, bean, and egg plant. Suitability is determined by host and parasite preference, and freedom of the host plant from attack by other insects.

Winter Rearing

The period when the parasites are reared in the greenhouse (from September to June) corresponds with the period of greatest activity in commercial greenhouses. During the entire period a surplus is maintained to supply requests from growers. To do this there must be at all times sufficient healthy host plants in the proper stage of development for infestation. Tobacco and tomato seed is planted about July 10, and at frequent intervals throughout the season. Seed germination and plant growth is slow and uncertain during October, November, December and early January, and to provide suitable plants during those months, seed is planted at 2-week intervals. Later in the season when growing conditions are more satisfactory, seed is sown at intervals of 4 weeks.

Production of Disease-free Host Plants

The parasites are shipped in the pupal stage on the host plant leaves; it is, therefore, essential to produce only healthy plants. Seed selection is important, since both tomato and tobacco seed may carry the organisms of virus diseases. Fortunately it has been possible to secure disease-free seed from the St. Catharines Plant Pathology Laboratory, through Dr. Berkeley, the officer-in-charge. Dr. Berkeley has also kindly provided a

simple method of determining the presence of virus disease in growing plants. By this method infected plants can be detected and destroyed as soon as suspicious symptoms are noted.

Artificial Light

Artificial light was tested for a period of three years. Lights of intensities varying from 25 to 100 watts were suspended at different distances from the growing plants. The results may be summarized as follows:

Host Plants: Tomatoes produced more suitable foliage during late autumn and early winter. Tobacco was brought into bloom earlier and matured more rapidly (an unsatisfactory condition).

Host Insects and Parasites: The proportion of parasites increased slightly when 100-watt lights were used. This may have been due to a slight increase in temperature caused by the heat from the lights. Lights of each intensity used attracted both whiteflies and parasites, and large numbers were killed. For this reason artificial light has been discontinued.

Temperature

Temperature is probably the most important single factor in the production of *Encarsia formosa*. It is by the regulation of temperature and the proportion of tomatoes and tobacco, which will be discussed later, that the required number and the proper proportion of hosts and parasites are maintained. The general effect of temperature was worked out by Speyer. To state it briefly, high temperatures favour the increase of the parasite and low temperatures favour the whitefly. In Canada it has been found that if the mean temperature is between 50° and 60° F., the whitefly can be expected to increase. Between 60° and 75° the proportion of parasites increases. A mean temperature below 50° or above 75° is unsuitable for either host or parasite. Temperature must also be considered from the point of view of host plant propagation. During autumn and early winter, usually from October through January, a comparatively low temperature is necessary for satisfactory plant growth. A high temperature produces rapid soft growth that breaks down quickly when subjected to heavy insect infestation. It has been found that a night temperature of 58°, supplemented by a day temperature of 60° or over, depending upon the intensity and amount of sunlight, is satisfactory for plant growth and parasite development. After January, the temperature may be raised to a mean of 65° or slightly higher.

Temperature is also important in its effect on the length of life cycle. Investigations both in Canada and England have shown that the average time required to complete the life cycle from egg to adult is from 28 to 30 days; the period may be shorter or very much longer, depending upon the temperature. Although hibernation has not been induced, development in the late larval and pupal stages is retarded by storage, at low temperatures, as shown in Table 1.

The ability of the parasite to withstand a period of 3 or 4 weeks of storage at 42° F., is as indicated in Table 1, is useful in maintaining a supply between crops. It is in the period between the time when one crop

TABLE 1.—RESULTS OF STORAGE OF *Encarsia* IN THE LATE LARVAL AND PUPAL STAGES

Period of storage	Temperature	Percent emergence	Average period from egg to adult
18 hours	12° F.	51	29 days
18 hours	20	88	30 days
7 days	42	95	34 days
14 days	42	86	40 days
21 days	42	55.5	45 days
28 days	42	22	51 days
35 days	42	0	—
*0		91.8	28 days

* Check lot reared through to emergence at room temperatures, 60° to 70° F., without any storage period.

is removed and the next one is planted that the parasite population is often greatly reduced or lost entirely. If parasite material is placed in storage during this period, it is much easier to maintain a continuous supply.

The average emergence of parasites from all material used for storage (2000) was 77%, while the emergence of whiteflies under the same conditions was 6%. The parasite is apparently better able to withstand the reduction in moisture, due to the drying out of the leaves after removal from the host plant.

Humidity

It is difficult to measure the humidity requirements of *Encarsia formosa*. The immature stages are not affected except through the host. An emergence of 100% adults has been secured at relative humidities ranging from 30% to more than 80%. Adults are more susceptible to humidity, and the length of adult life is considerably shortened by low humidity.

Host Plants

Investigations to date indicate that no species of plant is absolutely repellent to the parasite. Speyer, in developing rearing technique, found that tobacco was repellent to *Encarsia* and could be used to advantage in maintaining the supply of host insects. The results at the Dominion Parasite Laboratory have been somewhat contradictory. The parasitism on tobacco has fluctuated markedly from year to year, but has been consistently higher on the broad leaf cigar type tobacco than on the narrow leaf flue cure type. The degree of preference for host plants exhibited by both host and parasite shows great variation, even within the same species of plant. The reason for this preference is not known.

Parasitism of whitefly by *Encarsia formosa* has been secured in varying degrees on a large number of weeds, and the following vegetables and flowers: tomato, bean, squash, pumpkin, cucumber, egg plant, tobacco, potato, lettuce; fuchsia, pelargonium, primula, aster, salvia, lantana, petunia, poinsettia, coleus, variegated maple, gardenia, geranium, calceolaria, morning glory, and hollyhock.

DISTRIBUTION TO GROWERS

Encarsia formosa is distributed in the pupal stage. Infested leaves are removed from the host plants and examined. Whitefly scales that are not parasitized are destroyed with dissecting needles. The leaves are

placed in waxed paper and then rolled in bundles to fit cardboard tubes, each of which contains from 1000 to 5000 parasite pupae. The tubes are wrapped with ordinary wrapping paper and shipped by parcel post. A mimeographed sheet of directions is enclosed with each shipment to ensure proper handling of the material by the grower who receives it. This method of distribution has proven satisfactory, and shipments have been made to all parts of Canada with excellent results.

The number of parasites required to control an infestation is determined from a consideration of all the information available. To obtain the best results, it is necessary to know: the area under glass, area infested, crops infested, degree of infestation, stage of development of the crops, and the temperature at which the crops are grown.

(1) The Area Under Glass.—This information is used for purposes of record and is necessary because it has been found that larger areas require proportionately fewer parasites than do smaller areas.

(2) Area Infested.—The number of parasites required for control on a given crop is based upon the number of square feet of infested area.

(3) Crops Infested.—Some crops require more parasites than others. For example, two greenhouses each with an area of 1,000 square feet are planted with tomatoes and primulas respectively:

	No. 1	*No. 2*
Area	1,000 sq. ft.	1,000 sq. ft.
Crop	Tomatoes	Primulas
No. of plants	500	5,700
No. of whiteflies per plant	3	3
Total no. of whiteflies	1,500	17,100

Given the same population of whiteflies per plant, the total population increases proportionately with the number and size of plants infested.

A knowledge of the crops infested is important also because, if several crops are present, the parasites occasionally show a host plant preference, and unless a large parasite population is present, satisfactory control of the pest is not secured.

(4) Degree of Infestation.—The degree of infestation is important since it gives an indication of the total population. It also indicates whether the parasites can be expected to control the infestation unassisted. If the infestation is such that it cannot be controlled quickly, a light fumigation to kill the adult whiteflies is advised. The following quotation is taken from the instructions sent out with each shipment of parasites. "In case a severe infestation of whitefly is already present, and fumigation is possible it would be advisable to give a very light fumigation with hydrocyanic acid gas immediately before the parasites are placed in the house. This will kill the majority of the adult whiteflies and leave the young stages of the fly alive for the parasites to breed in."

(5) Stage of Development of the Crops.—A crop that is nearing maturity has a larger population than a new crop and, therefore, requires more parasites.

(6) The Temperature at which the Crops are Grown.—As was stated earlier in this paper, temperature is one of the most important factors in the rearing of *Encarsia*. It is also important in deciding the number of parasites necessary to control an infestation of whitefly. If the temperature is near the optimum, fewer parasites are required than if it is higher or lower.

After a consideration of the above imformation, or as much of it as is available, an estimate is made of the number of parasites required. Usually from 1000 to 2000 parasites per thousand square feet of greenhouse space are sufficient to control an infestation. If more than 3000 parasites per thousand square feet are necessary, better results can be expected if a light fumigation is carried out before the parasites are introduced.

The practical value of this parasite has been demonstrated by its effective control of the whitefly on many varieties of plants and over a wide range of greenhouse conditions. Its use is increasing and should continue to increase as growers become more familiar with its use and possibilities.

In addition to the economy of this method of control it makes possible the growing of certain varieties of susceptible plants under conditions where fumigation or other treatment cannot be carried out, and also the growing of crops that would be severely injured or destroyed by fumigation. Some idea of the increasing use of *Encarsia formosa* may be obtained from the steadily increasing number sent out from the laboratory. In 1935 the shipments amounted to 230,800; in 1936, 326,160; and in 1937, 602,000 parasites. Shipments are made only on the request of growers, and a large portion of the increased demand has come from growers who have used the parasites with success in previous years, and those who have learned of their successful use by others.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

III. THE FLIGHT OF THE EUROPEAN CORN BORER. THE INFLUENCE OF THE PHYSICAL FACTORS UPON FLIGHT

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(A) Temperature

The Optimal Temperature of Flight

The number of moths flying in plots "A" and "B" during the last ten years are plotted against the temperature at which they were observed in flight in Figure 1. This is done without considering any other factor. Because of the length of observations the data should give a close approximation to the temperature preferred by the moths for flight.

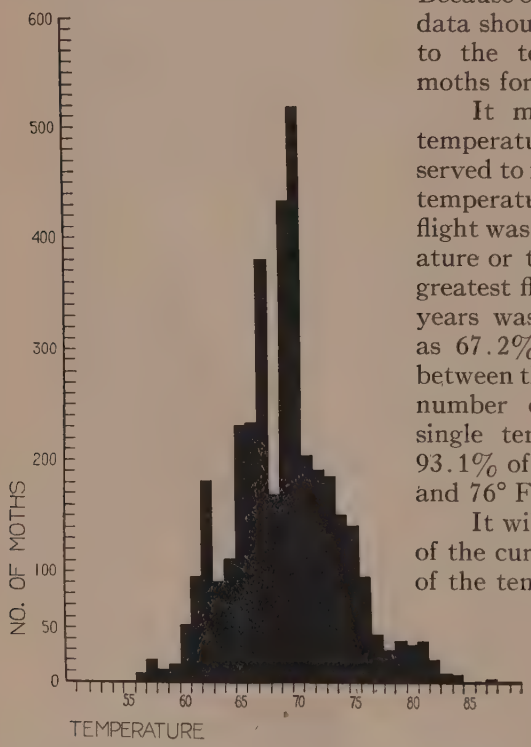

FIGURE 1. Temperature at which flight of moths took place, Plots A and B, Chatham, Ontario, 1927-36.

It may be seen that the lowest temperature at which moths were observed to fly was 56° F., while the highest temperature at which moths were in flight was 87° F. The optimum temperature or the temperature at which the greatest flight activity took place for all years was between 65° F. and 70° F., as 67.2% of all moths observed flew between these temperatures. The largest number of moths observed for any single temperature occurred at 70° F.; 93.1% of all moths flew between 60° F. and 76° F.

It will be noted also from the shape of the curve in Figure 1 that a lowering of the temperature from 65° F. inhibits flight very quickly, while an increase in temperature above 75° F. decreased flight much more gradually. In other words, the moths react more quickly to low temperatures than they do to high temperatures.

[1] Entomologist in charge.

An exploratory histogram of the data as to the temperature at which the individual sexes flew was made and it was found that no difference in the temperature at which males and females fly could be detected. Both sexes have the same general flight temperature relations as shown in Figure 1 in which sexes are combined.

The Graphic Presentation of the Relationship of Flight to Temperature and other Factors

A study of the effects of temperature and other factors in individual years and for individual nights is given below. These effects may be studied more effectively when the factors are plotted upon the same graphs as the flight in the various plots. This is done for each year in charts, Figures 2 to 11. The values for temperature, saturation deficiency, relative humidity and wind, are the average for each night for the duration of evening flight. This is generally the period from 7:30 p.m., to 12:30 a.m., or for the number of observations taken on the particular night. Temperature is in degrees Fahrenheit, saturation deficiency in millimetres of mercury of vapor pressure, and wind is in feet per minute.

The Regulative Action of Temperature upon Flight

A study of Figures 2 to 11 shows a very remarkable correspondence in the variations of the relative number of moths observed in the two field plots and in the light trap from night to night. A more remarkable correlation is seen to exist between the fluctuations in temperature and the fluctuation in the number of moths in each plot or in the light trap. A rise in temperature shows an increase in the number of moths in flight and a decrease in temperature shows a decrease in the number of moths or cessation of flight, if the temperature is low enough. Peaks in moth flight agree with peaks in temperature, while depressions in flight agree with depressions in temperature. There are very few exceptions to this correlation.

A general discussion of temperature and flight in each year follows:

Year 1927. This was a relatively cool year as can be seen by the low position of the temperature curve in relation to its base. Humidity was high, as indicated by the very high position of the relative humidity curve and the relatively low saturation deficiency curve. Wind was relatively low throughout the year. It was probably the least windy of any year at the time of flight, The flight curve agrees well with that of temperature, major peaks of flight occurred at the major peaks of the temperature curve. Moth flight was prohibited on July 19, 29, August 1 and 2, by low temperature.

Year 1928. This was another comparatively cool year during flight as shown by the low position of the temperature curve, although three medium-placed peaks in temperature occurred. Humidity was high as shown by the low saturation deficiency curve. Wind was very low. The peaks and depressions of flight agree with those of temperature except on July 10 when with a fairly high temperature, no moths were secured. The only apparent reason for this discrepancy is the fact that only two hourly records were taken on this night instead of the usual number and the moths did not fly until later in the evening after the observations were made, although moths had flown during the two early observations, before

and after this date. Moth flight was prohibited by low temperature on July 13, 28, 29. There is no discernible reason for their absence on August 1 unless it was the nearness of this date to the termination of flight.

Year 1929. This was an intermediate year in the value of the physical factors. Temperature was fairly low during the beginning of the period, followed by a period in which it was quite high. Relative humidity was generally high as shown by the low saturation deficiency curve. Wind was low except for two peaks. Plots A and B are almost exactly alike in their variations in numbers of moths in flight and both follow the temperature curve very closely. The absence of moths in plot A on July 6 is unexplainable. Five observations were made in the plot. In plot B, on the other hand, two moths were secured. This variation might be due to the comparative earliness of the night in the flight season. Moth flight was prohibited on July 19 and July 20 by low temperature, although one moth was secured in plot B during the first observation hour, when the temperature was 59° F. After this hour, the temperature fell rapidly.

Year 1930. Temperature in this year was fairly high with a very hot period during the latter portion of flight. Humidity was fairly high at first, but low during the period of high temperature. Wind was variable, but moderately high. In general, it was a normal year, with a hot, dry period toward the end of flight. The moth flight curve and that of

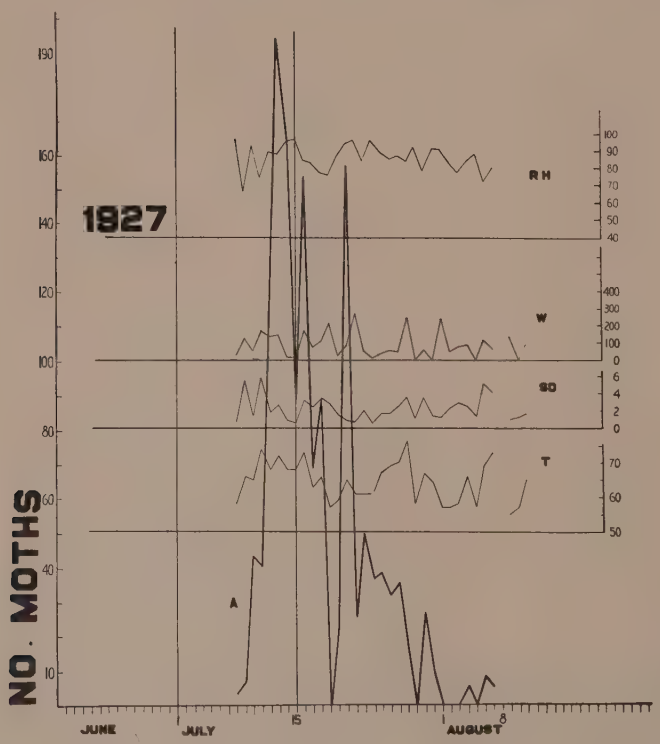

FIGURE 2. Relationship of flight to certain physical factors, Chatham, Ontario, 1927. A—Daily flight of moths, Plot A.

T—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

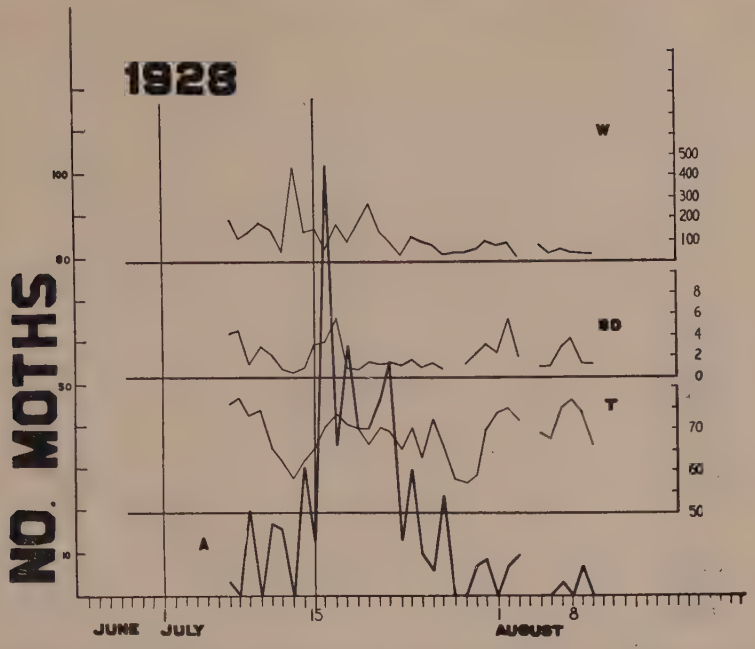

FIGURE 3. Relationship of flight to certain physical factors, Chatham, Ontario, 1928. A—Daily flight of moths, Plot A.

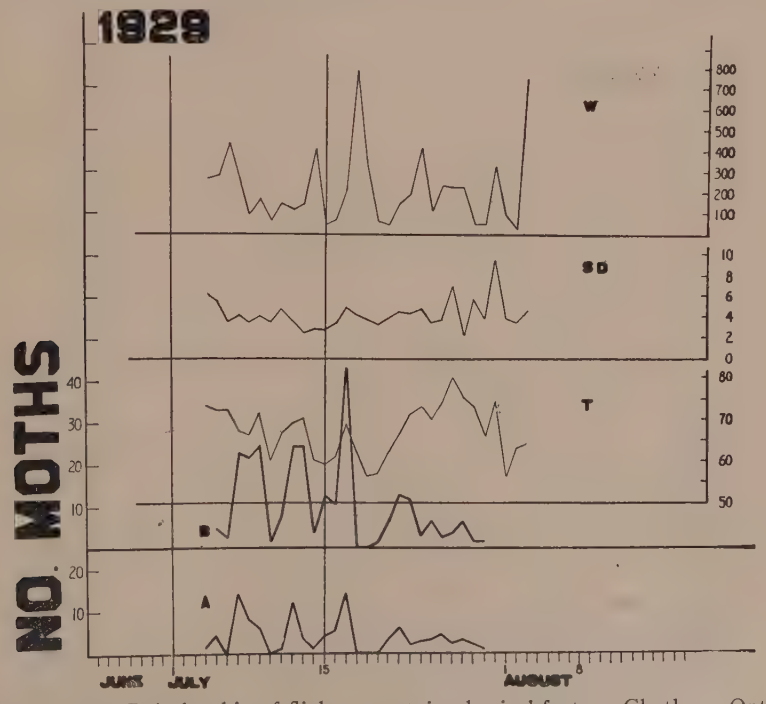

FIGURE 4. Relationship of flight to certain physical factors, Chatham, Ontario 1929. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B.

T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

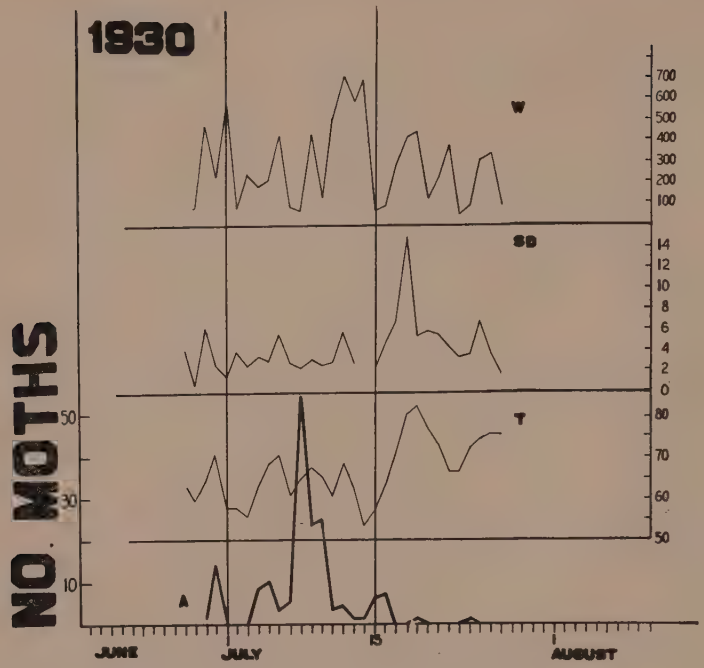

FIGURE 5. Relationship of flight to certain physical factors, Chatham, Ontario, 1930. A—Daily flight of moths, Plot A.

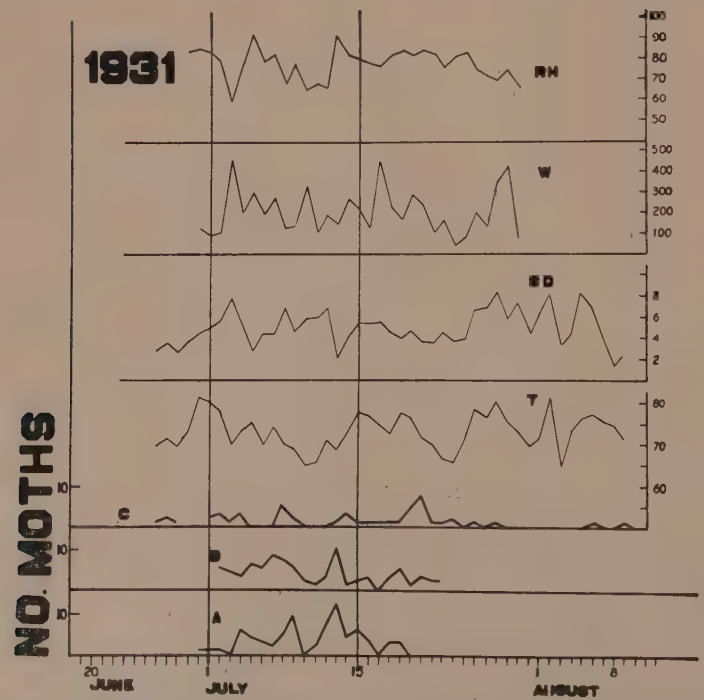

FIGURE 6. Relationship of flight to certain physical factors, Chatham, Ontario, 1931. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

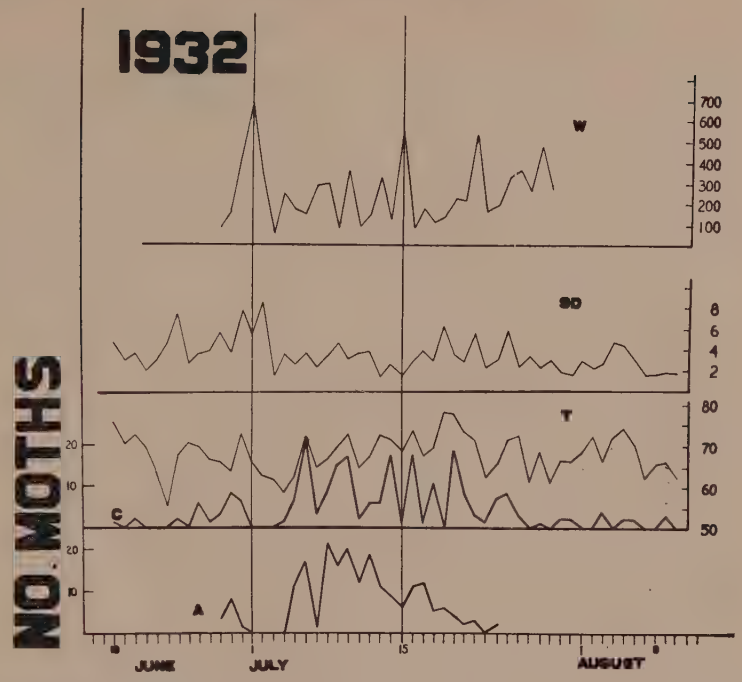

FIGURE 7. Relationship of flight to certain physical factors, Chatham, Ontario, 1932. A—Daily flight of moths, Plot A; C—Daily flight of moths to light trap.

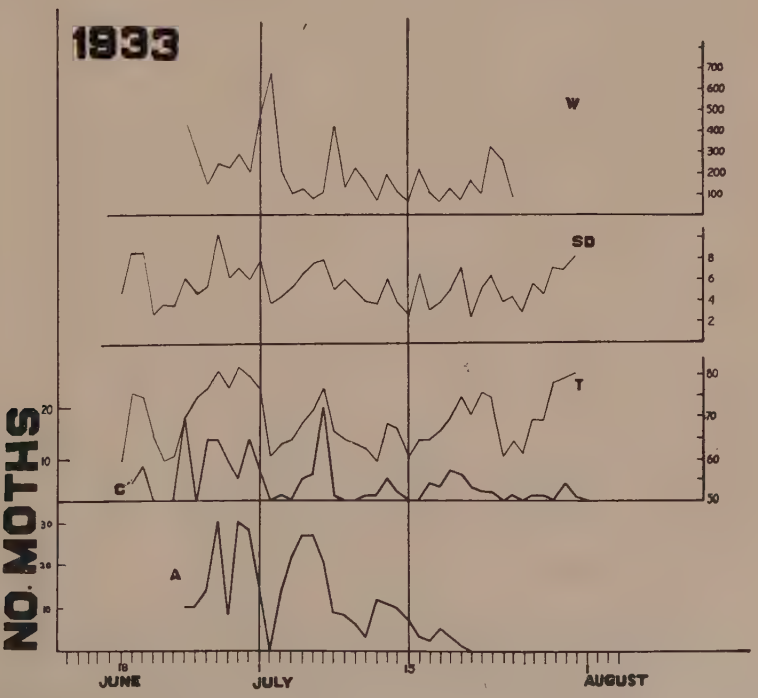

FIGURE 8. Relationship of flight to certain physical factors, Chatham, Ontario, 1933. A—Daily flight of moths, Plot A; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

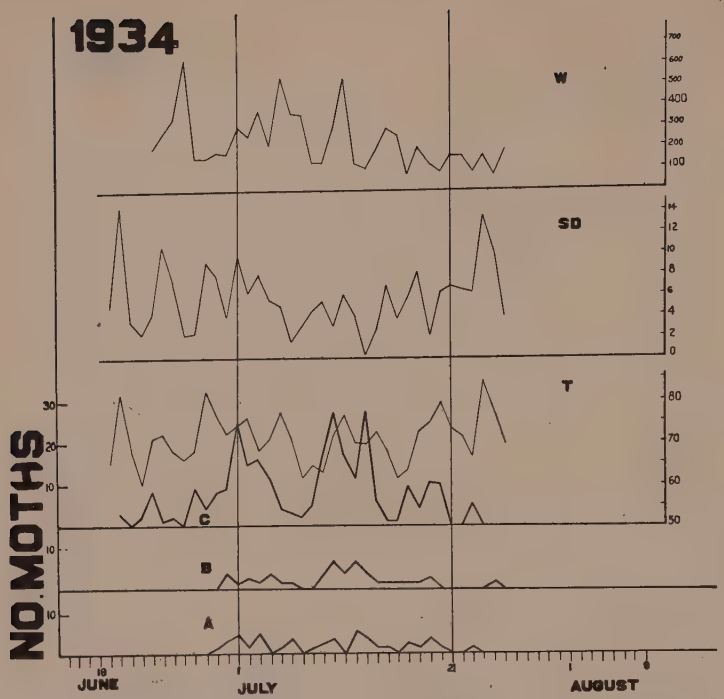

FIGURE 9. Relationship of flight to certain physical factors, Chatham, Ontario, 1934. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

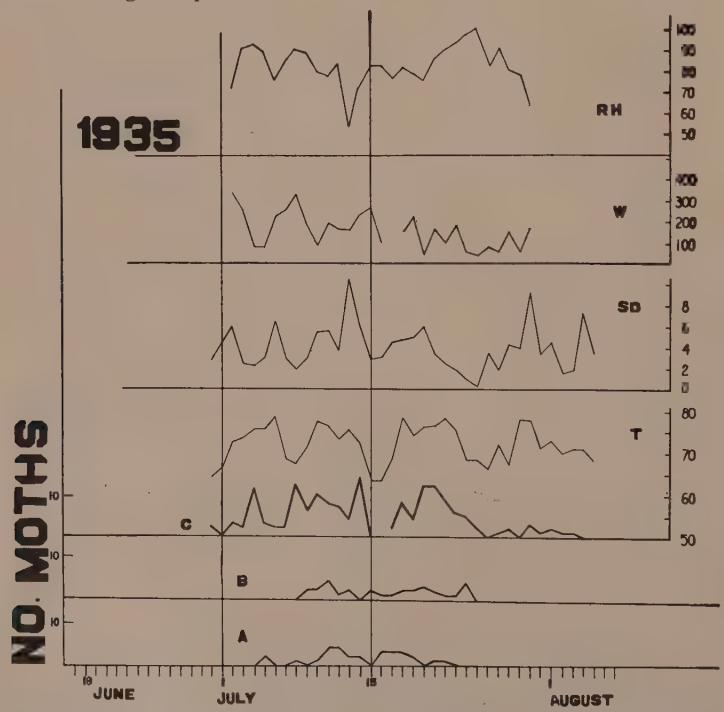

FIGURE 10. Relationship of flight to certain physical factors, Chatham, Ontario, 1935. A—Daily flight of moths, Plot A; B—Daily flight of moths, Plot B; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, W.—Mean wind velocity, and R.H.—Mean relative humidity, respectively, for daily period of observation.

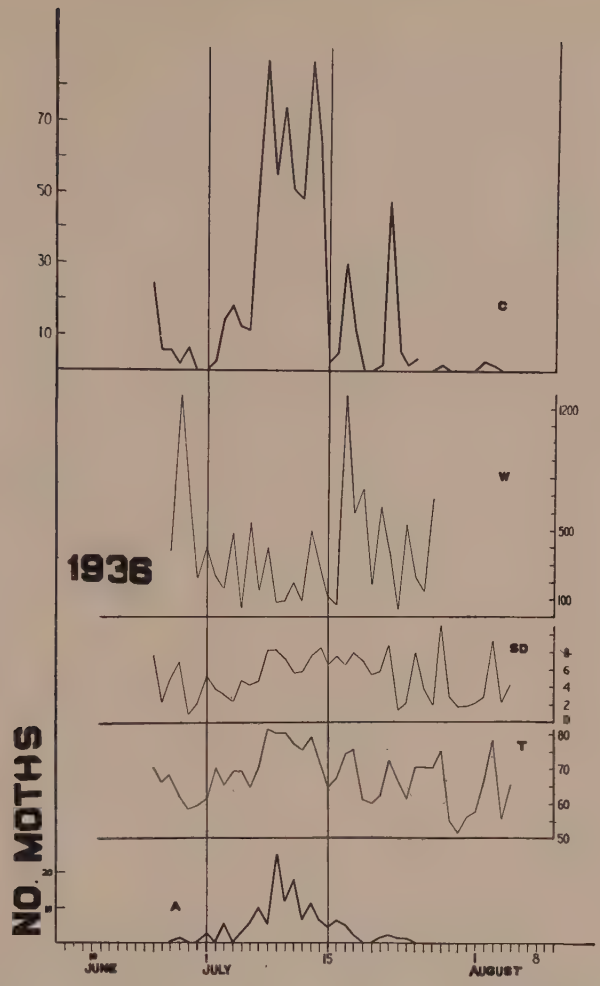

FIGURE 11. Relationship of flight to certain physical factors, Chatham, Ontario, 1936. A—Daily flight of moths, Plot A; C—Daily flight of moths to light trap.

T.—Mean temperature, S.D.—Mean saturation deficit, and W.—Mean wind velocity, respectively, for daily period of observation.

temperature agree uniformly, possibly more so than for some of the other years. Moths were absent from the field because of low temperatures on July 1, 2, 3, 14 and 15. On July 18 and 19, the temperature was 80° F. and 82° F. respectively. At time of first observation, July 18, the humidity was very low, but on July 19 it was moderately high. It would appear that perhaps this hot, dry period prohibited flight as moths were taken before and after the period.

Year 1931. This year was characterized by high temperature throughout the period of flight. The humidity was average, but higher than in previous years. Wind was on the average, low. There is a general agreement between moth flight and temperature. The absence of moths in plot A on July 3 and July 10 is not due to meteorological factors as moths were flying in plot B on these nights. The absence of moths in both plots

on July 17 is unexplained; the temperature was high, humidity fairly high and wind, moderate. There were fewer moths in flight in the plot during this year than for any previous one and the light trap catch was also very low when compared to later years.

Year 1932. This year was characterized by a moderate temperature with a fairly high humidity. Wind was about average. The major peaks and depressions agree in plots A and C, and both agree with the rise and fall in temperature. On July 4, flight was prohibited by a drop in temperature early in the evening. At −:30 o'clock, the temperature was 63° F., but by the next hour it was 58° F. On July 1, 2, 3, the mean temperature was just below 60° F., but a detailed study of the records shows that the actual temperature on these three nights was below 58° F. by 2:30 Sunset time and hence, prohibited flight.

Year 1933. Temperature in this year was comparatively low. A detailed study of the primary data shows that this year was cold just before and after midnight on many occasions. It was unique in this respect. The humidity was fairly low at first, but soon became higher. Wind was average. The moth flight peaks agree in plots A and C and both follow the temperature curve to a remarkable extent. A temperature rise gives an increase in number of moths in every case except one. Flight was prohibited on July 2, while on July 12 the flight was terminated early because of a drop in temperature.

Year 1934. This year was characterized by high temperatures with comparatively low humidity. Wind was average. The flight of moths to plots A and B were small, while the light trap catch, C, was about average. The three curves agree in two peaks and two major depressions. All show a relationship to temperature, but C is best to follow because of its larger number of moths. The minor variations in this year are not in very close agreement with those of other years. This may be due to the small number of specimens observed. In many cases, there is no apparent reason for lack of flight as flight would occur in one plot and not in another.

Year 1935. The temperature was comparatively high, while the humidity curve is moderately placed as shown both by relative humidity and saturation deficiency curves. The three flight plots, A, B and C, all agree in their major variations and all are in close agreement with the temperature curve except in two cases. The flights in plots A and B, as well as in C, are small and therefore probably give the most inaccurate record of any year, but even here the major flight peaks and depressions follow those of temperature.

Year 1936. This year was characterized by a very high temperature, especially during the middle portion of flight. The humidity was low, the lowest of any year. Wind was fairly high, with high peaks. It was the windiest year observed. Even with the high temperatures, low humidity and high winds of this year, the moth flight curves of plots A and C follow very closely that of temperature.

The Effect of Temperature on Flight during Individual Nights

The effect of temperature upon flight is strikingly shown within an individual night. On certain nights the temperature may be high enough

to allow flight in the early portion of the evening, but falls rapidly and prohibits flight. This effect can readily be seen in the selected nights shown in Table 1.

TABLE 1.—PROHIBITIVE EFFECT OF LOW TEMPERATURE ON FLIGHT, WITHIN INDIVIDUAL NIGHTS, CHATHAM, ONTARIO

Date	Hour	Temp.	Rel. hum.	Evaporation	Satur. deficit	Wind	Precipitation	No. of moths	
								A	B
July 20, 1927	:30	63	77	—	3.30	83	00	12	
	1:30	57	94	—	0.74	00	00	15	
	2:30	56	91	—	0.99	00	00	0	
July 30, 1928	:30	62	72	.09	3.95	82	00	7	
	1:30	56	89	.02	1.29	36	00	0	
July 10, 1929	:30	64	63	.09	5.66	142	00	1	
	1:30	60	73	.03	3.60	36	00	0	
	2:30	57	85	.00	1.68	36	00	0	
July 21, 1929	:30	65	58	.09	6.67	36	00	1	2
	1:30	61	72	.02	3.80	73	00	2	4
	2:30	59	80	.01	2.35	61	00	0	0
July 7, 1930	:30	64	71	.10	4.44	100	00	1	
	1:30	60	80	.02	2.53	55	00	2	
	2:30	58	83	.04	2.08	62	00	2	
	3:30	56	90	.08	1.14	36	00	0	
July 12, 1933	—:30	70	54	—	8.63	36	00	3	
	:30	62	68	.02	4.55	36	00	5	
	1:30	58	80	.02	2.48	36	00	2	
	2:30	56	85	.02	1.73	36	00	2	
	3:30	54	87	.00	1.44	82	00	0	
	4:30	53	89	.00	1.44	36	00	0	
	5:30	53	90	.00	1.04	36	00	0	

Temperatures from 59° F. to 56° F. not only prohibit flight altogether if they occur early enough in the evening, but prohibit flight whenever they occur in the nightly flight cycle.

If temperature on individual nights has such a great influence on the flight of moths, one must consider what the effect of the general character of the season in regard to temperature would have upon flight. As pointed out above, 1927 and 1928 were comparatively cool years, while 1931, 1934 and 1936, in particular, were warm years. This consideration will be taken up later, after the remaining physical factors have been discussed. It might be mentioned here, however, that it would appear as if the seasonal night temperatures had very little effect in lengthening or curtailing flight, although 1931 and 1935 had the shortest flight seasons and both were warm years.

A Review of the Literature on the Effect of Temperature on Flight

In the literature dealing with the European corn borer, most of the references deal with the effect of temperature upon flight through the association of egg-laying activity. These references will be dealt with later.

Stirrett (13) found that in the early years of the present study, no moths flew when the temperature reached as low as 57° F. Huber (9) gives data showing the numbers of moths caught at definite temperatures, but does not discuss the effect on flight proper except through egg-laying activity. Hervey and Palm (7) found that in New York, in 1933, temperatures between 70° F. and 75° F., were most favourable for flight. At mean temperatures, below 70° F., the moth catch dropped off rather rapidly and below a mean of 60° F., the activity was much retarded. The mean temperature used by them was that of the temperature between 8:00 p.m. and 4:00 a.m.

There is a very close agreement between the findings of Hervey and Palm and our own work as to the optimum and range of temperatures at which the flight of moths takes place.

Among other Lepidoptera, several authors have studied the effect of temperature on flight. According to Uvarov (14) who gives a very good summary of the literature up to 1930 upon Lepidoptera and other insects, most of the authors have found a positive correlation between temperature and flight activities, although Ainslie (1) concluded that the flight of crambid adults was not correlated with temperature. Cook (5) made extensive studies upon the flight of various species of noctuid moths and found temperature had a positive effect upon the number of moths captured, especially was this so when the humidity was low.

Yothers (16) found a definite relationship between codling moth activity and temperature. Most codling moths were captured when the mean daily temperature was above 70° F. A sudden drop in temperature practically prohibited all flight until it warmed again.

Collins and Nixon (4) found the optimum temperature for the flight of *Eucosma ocellana* Schiff. to be between 65° F. and 70° F. They found a positive correlation at other temperature ranges also, and noted that few Lepidoptera fly when the temperature falls below 60° F.

This last observation is very nearly parallel to observations made many times during the present study, that when the temperature is around 60° F. or below, very little insect life of any type and especially of Lepidoptera, was noticed in the field. Such a night was July 2, 1933, when no corn borer adults or insect life of any kind was noticed in flight. The character of the night is shown in Table 2 as measured by hourly observations according to Sunset time.

TABLE 2.—THE PHYSICAL FACTORS, JULY 2, 1933, TO SHOW TYPE OF NIGHT IN WHICH NO INSECTS OF ANY KIND WERE NOTED IN FLIGHT IN CORN FIELDS

Sunset time	Temp.	Rel. hum.	Evap.	Sat. def.	Wind vel.	Precipitation
−:30	64	75	.08	3.84	700	00
:30	61	74	.08	3.55	818	00
1:30	60	71	.09	3.85	732	00
2:30	59	73	.05	3.43	551	00
3:30	58	78	.02	2.72	424	00
4:30	56	78	.04	2.53	616	00
5:30	56	73	.04	3.07	571	00

It would appear from the present work and from the above review of the literature that with very few exceptions flight is directly correlated with temperature and that temperatures below 60° F. have a marked

effect in retarding flight. The optimum temperature for the flight of the borer adult is very close to that for *Eucosma ocellana* Schiff., and other nocturnal Lepidoptera.

(B) Humidity

Humidity was measured as saturation deficiency expressed as a vapour pressure in millimetres of mercury and as relative humidity. Throughout the discussion it is referred to under "saturation deficiency". In Figures 2, 6 and 10, however, relative humidity is also plotted and discussed for the years treated in these figures.

The Optimum Humidity of Flight

The number of moths flying in plots A and B during the last ten years are plotted against humidity as shown by the saturation deficiency in Figure 12. This is done without considering the influence of any other factor. Because of the length of observations the data should give a close approximation to the humidity preferred by the moths for flight. It will be seen from Figure 12 that moths flew mostly during high humidity periods: 38% of the moths flew between a saturation deficiency of 0 and 2 mm.; 89% flew between a saturation deficiency of 0 and 6 mm.

An exploratory histogram was made from the data to see if sexual preferences existed in the flight at various humidities, but none could be found. Both sexes appear to have the same preferences of humidity for flight.

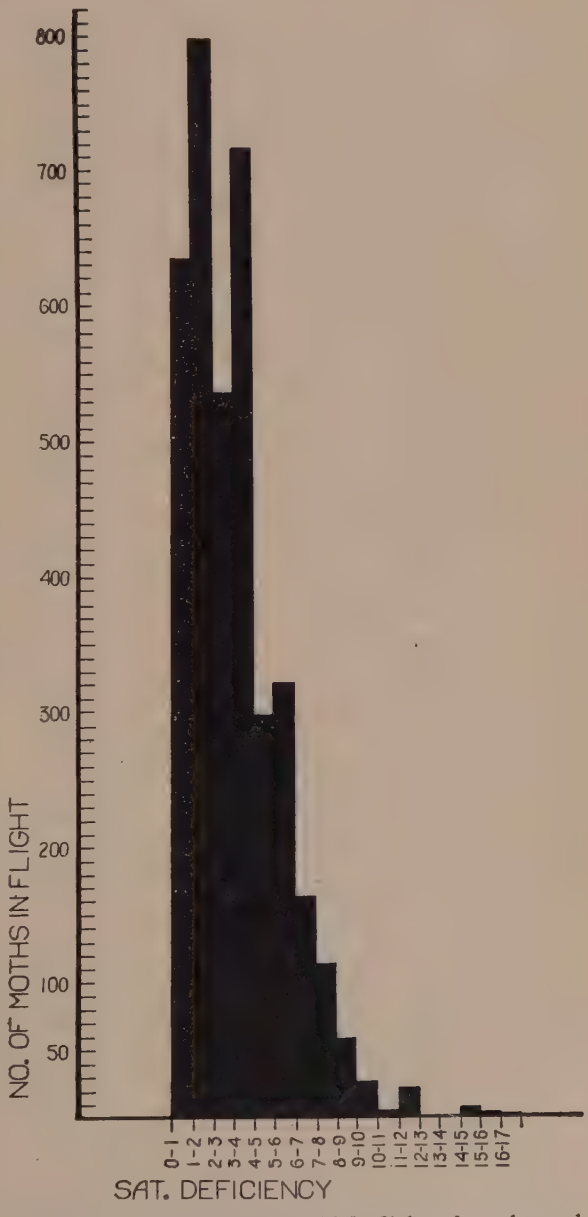

FIGURE 12. Humidity at which flight of moths took place, Plots A and B, Chatham, Ontario, 1927–36.

The Effect of Humidity upon Nightly Flight

From a study of Figures 2 to 11, the character of each flight season and each individual night as regards humidity can be seen and studied.

The year 1927 was one of high humidities at the time of flight as shown by the low saturation deficiency curve and the highly placed relative humidity curve. The curve of flight does not seem to have any relationship to the curves of humidity.

The year 1928 was also a year of high humidity at the time of flight as shown by the low saturation deficiency curve. The average saturation deficiency for any night did not reach 6 mm. The curve does not bear any relation to that of flight.

The year 1929 was not quite as humid during the time of flight as either 1927 or 1928. The curve is higher on the scale. No relationship is shown between moth flight and saturation deficiency.

The year 1930 was much like the year 1929 in its atmospheric moisture relations in the early period of flight, but a very hot, dry period occurred about July 18. Flight terminated abruptly, but whether it was the natural termination of flight or the effect of low humidity or high temperature, or both, is unknown. No correlation exists between flight and saturation deficiency.

The year 1931 was relatively dry during the period of flight. No relationship between moth flight and humidity is indicated for any of the three flight curves.

In the year 1932, humidity was somewhat higher than in 1931 as is shown by the position of the saturation deficiency curve on the chart. No relation is apparent between flight and humidity.

In the year 1933, the humidity was about the same as in the year 1931. These two years are halfway between the years of highest humidity and those of lowest humidity. No relationship is indicated between moth flight and humidity, even when the temperature is relatively high as in the last few days in June.

The years 1934 and 1936 were relatively dry years with the lowest humidities of any of the years studied. They also showed the greatest variations from night to night. In the year 1934, there does not appear to be any correlation between moth flight and humidity, even when the temperature is comparatively high as during the last of June and the first of July.

The year 1935 is an intermediate one as far as humidity is concerned. It was much like the years 1931 and 1933, except that its period of lowest humidity occurred during the middle period of flight. There is an indication, on June 13, that flight might have been lessened because of low humidity during a high temperature period.

The year 1936, and the year 1934, as has been pointed out, were the two driest years encountered during the ten years under study. No relationship between flight and humidity can be seen from the curves of each in Figure 11.

From Figures 2 to 11, and from the summary given above for each year, it will be seen that humidity as encountered during the ten years and

as indicated by saturation deficiency has no influence upon the nightly variations in the flight of moths. This may be due to the fact that any effect humidity might have is masked by the greater response of the moths to changes in temperature.

It should be pointed out that moth flight takes place during the time of the day when humidity is naturally high. Only on a very few occasions did the average saturation deficiency reach 10 mm. during the observations.

The Effect of Humidity upon the Time of Night of Flight

An attempt was made to ascertain whether or not the humidity had an influence upon the time of night at which the moths begin to fly. Saturation deficiencies at similar temperatures were plotted against the time of flight of first moths in the evening and it was found that humidity was not a controlling factor on the time of flight.

The Effect of Humidity on the Flight of Nocturnal Lepidoptera

There is no literature referring to the effect of humidity upon the flight of the European corn borer. According to Uvarob (14), Picard, Necheles and Martini suggested that nocturnal insects are active at night because they require a high degree of humidity. In our own case, the humidity varied greatly at the time of commencement of moth activity and the humidity did not appear to have any influence over flight. Cook (5), in studying the flight of nocturnal Lepidoptera to light trap considered relative humidity the most important factor studied. Any increase in the 7:00 p.m. relative humidity up to 54% tended to increase the catch, while beyond this value it decreased the catch in almost the same proportion. Cook's work is not of great value as he measured humidity in terms of relative humidity at varying temperatures. He did not, therefore, know the exact state of the atmosphere in regard to humidity from night to night.

The effect of variations in humidity during the various seasons upon flight, oviposition and establishment is discussed again later.

(C) Wind

The effect of wind upon the flight of the European corn borer moth has never been adequately studied. Most of the work has been done in connection with the effect of winds in spreading the insect into new territory. This phase is not considered in the present paper. Huber (9) relates that relatively strong winds cause the moths to seek shelter on corn plants or if not flying over corn, on other plants nearby.

The average wind velocity for each night of observation is shown in Figures 2 to 11. Wind was measured in feet per minute. From a study of these figures it can be seen that the years 1927, 1928, 1931 and 1935 had low winds during the flight period, while during the years 1929, 1930, 1932, 1933, and 1934 the wind velocity was higher but variable. The wind obtained its highest velocity during the year 1936. A study of the curves of flight and the curves of wind velocity for any year fail to show a correlation between these two factors.

During the ten years, the wind velocity during flight observations ranged from 0 to 1492 feet per minute or from 0 to 17 miles per hour. Wind of such velocities did not lessen nor prohibit flight.

(D) Atmospheric Pressure

The influence of barometric pressure upon the activities of insects has been summarized by Uvarov (14). This author points out that insects are able to withstand enormous fluctuations in pressure such as can never occur in nature. Pressure in nature, therefore, cannot have a direct fatal effect upon insects.

Cook (5) studied the effect of pressure, temperature and humidity upon the numbers of moths caught in light traps. He concluded that barometric pressure had less influence than either temperature or humidity.

Rhumbler (12), in studying the flight of May-beetles (Melolontha), concluded that they begin to fly in the evening owing to the usual, slight, not over 0.1 mm. rise in barometric pressure which occurs every evening between 9:00 and 10:00 p.m.

In the present study, it was impossible to purchase a barometer until the spring of 1936. Previous to this date, barometric pressure readings were obtained from the Chatham Station of the Meteorological Service of Canada. The pressure was recorded at 8:00 a.m. each day. Exploratory histograms were made for the years 1927-35, inclusive, plotting numbers of moths in flight against barometric pressure, but no correlation was found to exist.

During the year 1936, barometric pressure was taken just before moth flight and at termination of moth flight in the same evening. These data are given in Table 3.

TABLE 3.—BAROMETRIC PRESSURE AT BEGINNING AND END OF DAILY MOTH FLIGHT AND NUMBER OF MOTHS IN FLIGHT, CHATHAM, ONTARIO, 1936.
PRESSURE IN INCHES OF MERCURY

Date	No. of moths in flight	Barometric pressure at beginning of flight	Barometric pressure at end of flight	Type of change in pressure amount		
				Rise	Fall	Amount
June 27	0	29.13	29.13	–	–	0
28	1	29.16	29.24	+		.08
29	0	29.07	–			
30	0	29.20	–			
July 1	2	29.32	29.34	+		.02
2	0	29.24	29.25	+		.01
3	5	29.34	29.32		+	.02
4	0	29.35	–			
5	3	29.48	29.51	+		.03
6	6	29.55	29.54		+	.01
7	10	29.33	29.34	+		.01
8	5	29.27	29.27	–	–	0
9	25	29.29	29.30	+		.01
10	11	29.24	29.26	+		.02
11	18	29.21	29.32	+		.11
12	6	–	–			
13	11	29.27	29.25		+	.02
14	6	29.14	29.27	+		.13
15	4	29.31	29.32	+		.01
16	6	–	29.28	–	–	
17	5	29.24	29.24	–	–	0
18	2	29.18	29.24	+		.06
19	0	29.24	29.28	+		.04
20	0	29.35	29.37	+		.02
21	1	29.35	29.37	+		.02
22	2	29.25	29.24		+	.01
23	1	29.11	–			
24	1	29.25	–			
25	0	29.18	29.23	+		.05

From Table 3 it can be seen that for 1936 there was no correlation between the number of moths in flight and the barometric pressure, either immediately before flight commenced or at the termination of flight. A rising or falling pressure apparently had no influence upon flight.

Under conditions at Chatham, Ontario, the slight rise in barometric pressure observed by Rhumbler, between 9:00 and 10:00 p.m. does not always occur.

(E) Rain Storms

Very few actual records of the effect of rainfall upon the flight of the corn borer exist. Huber (9) concluded from his work in Ohio that hard rains interfere with moth activity, although gentle rains do not necessarily stop flight, providing other conditions are favourable. Stirrett (13) has noted that rain sometimes prohibits moth flight.

The effect of rain storms occurring during the time of flight when all other factors were favourable to flight are synopsized in Table 4. The approximate rate of rain per hour is indicated, but this figure must be used in reference to the factors given under the heading "Remarks".

TABLE 4.—EFFECT OF RAIN ON MOTH FLIGHT—THE INFLUENCE OF RAIN WHEN TEMPERATURE, HUMIDITY, TIME OF OCCURRENCE AND OTHER FACTORS ARE FAVOURABLE TO FLIGHT

Date	Approx. amount of rain per hour, in inches	Effect on flight	Remarks
1927 July 13	.14	Prohibited	Between 8:00 and 10:00 p.m., variable. Moths flew before and after rain.
1927 July 14	.02	None	Light drizzle.
1927 July 21	—	None	Electric storm followed by light rain during time of flight.
1927 July 22	.47	Prohibited	Moths flew during light rain period, but did not fly during heavy rain; flew later when it rained lighter.
1928 July 18	.02	None	Light intermittent rain, early portion of flight.
1928 July 21	—	None	Light drizzle for short period.
1928 July 22	1.03	Prohibited	Very heavy rain between observation periods. In light rains immediately after heavy rain, moths flew.
1930 June 30	.06	None	Rain mostly between observational periods.
1931 July 5	—	None	Light rain.
1931 July 21	.22	Prohibited	Moths flew before and after, but not during rain.
1932 July 20	.024	None	Very light rain.
1932 July 21	.17	Prohibited	Severe electrical storm; moths began to fly two hours after storm.
1933 June 24	.05	None	
1933 June 25	.03	None	Much lighter rain during most of period.
1934 July 6	.04	None	Intermittent rain.
1934 July 19	.04	None	Trace of rain previous to 3:30 Sunset time. During this hour, 0.04″ rain fell and moths flew.
1936 July 23	.23	Prohibited	Severe electrical storm. Moths flew in light rain during last portion of storm.

Table 4 shows that if other factors are favourable, rain has to be at least at the rate of 0.14 inches per hour to prohibit flight. Moths fly in corn fields during light rains.

(F) Electric State of the Atmosphere

Marchal (11) considered that the vine moths were more active and flew in greater numbers just before a thunder-storm. Uvarov (14) points out that very little is known regarding the effects of thunder-storms upon insect life, but that there is a general impression that insects are more active just before storms. Gourdon (6), as quoted by Uvarov, on the other hand, concludes that the organization of the atmosphere during a thunder-storm causes insects to remain inactive for a long time after the storm owing to stupor produced by ozone.

Three electrical storms occurred in the progress of the observations at time of moth flight during the ten years under study. On July 21, 1927, a severe electrical storm occurred between 7:00 and 8:00 p.m.; no moths were observed before or during the storm. They were not flying before the storm as it was too early in the evening. Moths flew in numbers immediately after the storm and while it was still raining. Temperature was favourable for flight, being 65° F. In this case, the electric state of the atmosphere, due to the storm, did not prohibit flight immediately after the heavy rain was over.

The electrical storm of July 21, 1932, occurred between 7:30 and 8:30 p.m., and moths were not found in flight until two hours later. The temperature was high, the average for the period of observations being 73° F. Moths had been captured in flight at the observation periods under consideration the night before and again the night after the storm. It would appear that the moths were affected by the storm in some manner, but whether it was because of heavy rain or from stupor, as suggested by Gourdon, is not known.

The third interesting storm occurred on July 23, 1936. It took place early in the evening before moth flight had commenced. Moths were in flight immediately after the heavy portion of the storm, and while it was still raining. In this case, the storm did not affect moths in any manner except to prohibit their flight during the short period of heavy rain.

All three storms occurred so early in the evening that their effect upon numbers of moths flying just as they were approaching cannot be measured.

(G) Cloudiness

Records of cloudiness for each hour of the night in relation to flight were secured. In examining these records, it is very evident that the presence or absence of clouds, even at the same temperature, has no influence upon the flight of moths.

(H) Lunar Periodicity

Very little is known regarding the influence of moonlight upon insects. Hora (8) observed that the appearance of swarms of certain Mayflies in India coincided with a definite moon phase. Wheeler and Brown (15)

observed that the periodic swarming of a crustacean at Bermuda coincided with the two weeks of lunar cycle when the moon wanes from the last quarter to the first quarter of the new cycle. Chatanay (3) found that the number of moths caught at light and at baits is greatly influenced by moonlight.

Effect on Annual Cycle of Flight

The question has been raised as to whether or not moths begin to fly when the moon is full and therefore brightest or whether moths appear during the time when there is practically no moonlight. A variation in the time of appearance of moths in the field has been noted as has also a variation in the time of peak of flight. What influence, if any, has the moon upon these variations?

The phases of the moon, as they occurred at Chatham, Ontario, each summer during the flight period have been plotted, together with the moth flight in Figure 13. The solid black triangles represent the moon

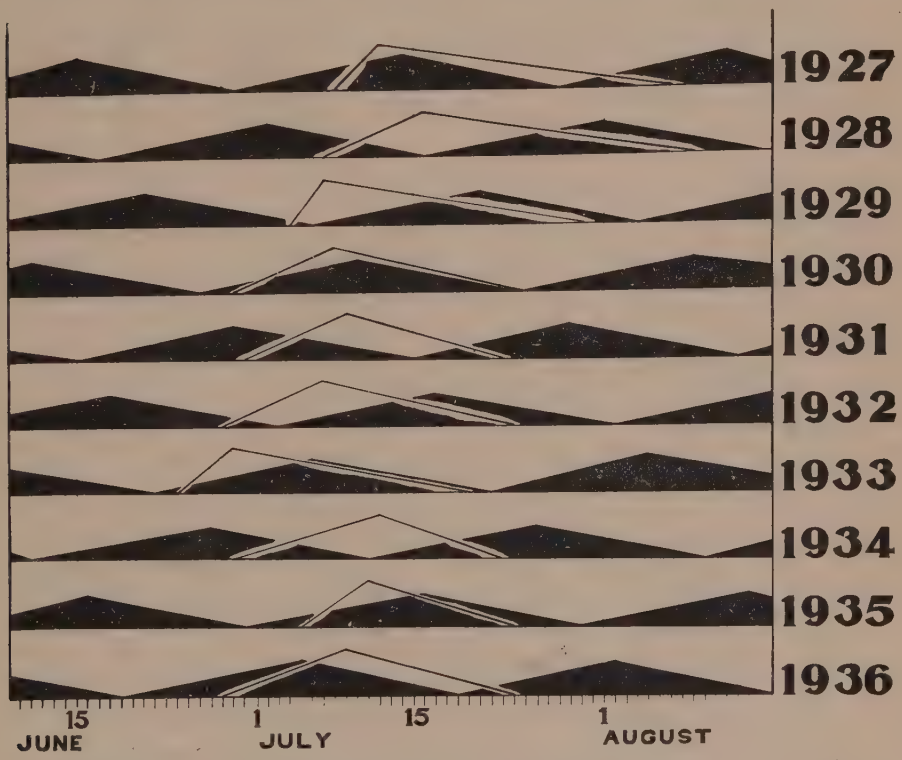

FIGURE 13. Relationship of the moth flight season with moon phases, Chatham, Ontario, 1927–36.

phases. The apex of the triangle is at the date on which the moon was full. The left basal point is at the date on which first quarter phase of the moon occurred and the right basal point is at the date of the last quarter. Beginning at the first quarter, the moon gradually becomes more brilliant until full moon is reached and then gradually wanes until last quarter. The flight of moths is represented by the solid black line. The peak of flight is at the apex of this line.

From Figure 13, it can be seen that the time of moth flight has no relationship to the time of occurrence of the full moon and therefore, no relationship to the intensity of moonlight. In 1927, for instance, moths began to fly during the latter part of the period of increase in moonlight, while in 1928, they began to fly when there was practically no moonlight. This was again the case in 1929. In 1930, moths began to fly during a period of increase in moonlight, but at an earlier date than in 1927. The peaks of flight in 1930, 1935 and 1936 are near the date of greatest amount of moonlight, but vary as to position before and after the peak of moonlight.

Effect within Flight Season

This factor may also be determined from Figure 13. It can be seen that the increase in the number of moths found in the field until finally the peak is reached cannot be correlated with the increase in the amount of moonlight. In 1928, 1931 and 1934, for instance, there was practically no moonlight during the time the moths were at their maximum activity.

The curves of flight in 1927 and 1929 are very similar, but the peak of flight in 1927 occurred just before the curve of maximum amount of moonlight, while in 1929 it occurred at the period of the new moon when there was practically no moonlight.

Effect on Nightly Cycle of Flight

The moon, in all its phases and during any particular phase, is not always visible at Chatham at the time of the day the moths are in flight. A record as to whether or not the moon was up or set and in or out (visible) for each hour of flight for all years was secured. From a detailed study of this record it can be seen that moths fly in numbers without relationship to whether the moon is brightly shining or whether it is not shining, either because it is behind clouds or set.

Table 5 gives selected records which show that moths commence to fly in the evening regardless of whether the moon is visible or not.

TABLE 5.—SELECTED RECORDS SHOWING EFFECT OF MOONLIGHT UPON FLIGHT OF MOTHS

Date	Hour, Sun-set time	Temp.	Saturation deficiency	Wind	Full moon	No. moths in flight
July 9	−:30	89	15.75	395	Set	0
	:30	82	9.78	147	Set	0
	1:30	79	7.21	333	Set	10
	2:30	78	6.39	296	Up and out	5
	3:30	76	5.97	777	Up and out	4
	4:30	75	4.28	376	Up and out	6
	5:30	74	3.06	231	Up and out	1
July 10	−:30	87	14.18	149	Set	0
	:30	82	8.63	28	Set	0
	1:30	81	8.11	107	Set	7
	2:30	78	5.15	27	Set	0
	3:30	78	5.15	57	Up, in and out	4
	4:30	75	2.88	32	Up, in and out	0
July 13	−:30	81	9.67	89	Set	0
	:30	80	6.24	99	Set	0
	1:30	79	7.21	23	Set	10
	2:30	79	7.21	24	Set	1
	3:30	76	8.03	89	Set	0

(I) Fog or Mist

Very little is known regarding the effect of mist upon the flight activities of insects. Uvarov (14) sums the present knowledge in a short paragraph. It would appear that mist reacts unfavourably to the flight of moths because it occurs generally upon cold nights when the temperature is too low for flight. Uvarov cites Rothke, however, as authority for the statement that certain insects, which are active at low temperatures, fly during misty nights.

Mist was encountered three times during the ten years' study upon flight. In 1927, there was a fairly thick fog on July 14, accompanied by a drizzle of rain. The temperature was 69° F., with a saturation deficiency of 0.51 and a wind speed of 25 feet per minute. Moths flew abundantly through rain and mist. In 1932, a fairly heavy mist was encountered in the early morning of July 21, while records were still being taken, but no moths had been seen after midnight. The mist occurred when moths were not in flight. The only other mist encountered was on the night of July 13, 1934. The temperature was 67° F., saturation deficiency 0.51, with no wind. Moths flew during the time mist was present.

Mists are rarely encountered during the flight season, but when they do occur and the temperature is favourable for flight, moths continue to fly during mists.

(J) Dew and Guttation

Free moisture, upon plants at night, whether derived as dew from the water vapour in the atmosphere or from the plant itself by guttation, and its relationship to insect activity has never been studied.

Records of the amount of dew present upon the corn plants were secured intermittently during the years 1927, 1932 and 1933, and complete records were taken during the years 1934, 1935 and 1936. Records of the amount of guttation were secured for the years 1935 and 1936.

It was found quite easy to identify water from dew and from guttation in the early part of the evening, but when dew becomes moderate or heavy it is not possible to distinguish the source of the water. Dew appears upon the upper surfaces of leaves and covers the surface of the plants within the field as well as other objects near the corn field, while water from guttation appears along the edges of the leaves and gathers at tip of leaf, and it is not present away from the plant. Water from guttation appears on the plants earlier in the evening than does water from dew. This can be seen from the accompanying record of July 15, 1935. Dew on

Sunset time	*Dew*	*Guttation*
—:30	None	Light
:30	None	Moderate
1:30	None	Very heavy
2:30	Moderate	Very heavy
3:30	Heavy	Very heavy
4:30	Heavy	Very heavy

this night did not appear until 2:30 Sunset time or approximately 10:30 p.m., Eastern Standard time, while water from guttation appeared as early as —:30 Sunset time or approximately 7:30 Eastern Standard time.

The amount of dew varies from year to year and from night to night within the year. In 1927 and 1928, dew was particularly heavy during flight observations, and operators were saturated with water while walking through the corn fields. In 1934 and 1935, there were a considerable number of nights without dew but on others it was quite heavy. The only year in which dew was absent from the fields was 1936. In this year dew occurred only upon three nights during the flight period. Guttation, on the other hand, produced considerable water on the plants during 1936 and in spite of the lack of dew the leaves were moist nearly every night. On a few nights with high temperatures (72° to 78° F.) neither dew nor water from guttation were present in 1936.

The Relationship of Dew and Guttation to Corn Borer Activity

It has been the general impression that adults and young larvae of the corn borer need and utilize free water, and that such is necessary for their well-being. Caffrey (2), for instance, records that moths sip pure water and live as long upon water as upon sugar syrup. Jablonowsky (10) observed moths in flight over clover fields and explained they were drinking dew from leaves and flowers. Dew and guttation have also been mentioned in a general way as a factor influencing larval establishment, although Huber (9) records that young larvae can apparently crawl through bubbles of water and water in the axils of corn leaves without harm.

From the observations upon the flight of moths, it is apparent that dew and guttation have no effect upon the numbers of moths in flight. This is what one would expect.

Dew frequently does not appear or does not become abundant until late in the nightly cycle of flight when the moths are terminating their flight.

In regard to the utilization of water from corn leaves for drinking by adults, it may be stated that no adults have ever been observed drinking in the corn field, but this does not prove or disprove that they do not do so. Adults are generally observed resting upon the central portion of the under side of leaves or upon the perpendicular culms where water from dew and guttation are not present.

(To be continued.)

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BOOK REVIEW

ARGLES, G. K.—A review of the literature on stock-scion incompatibility in fruit trees, with particular reference to pome and stone fruits. (Foreword by Prof. V. H. Blackman, Sc.D., F.R.S.). Technical Communication 9 of the Imperial Bureau of Fruit Production, East Malling, Kent, England, 1937, pp. 113, bibl. 194, 5/– .

The problem of incompatibility has loomed ever larger with the increasing realization of the advantages to be gained by the use of tested clonal rootstocks for the production of uniformly excellent fruit.

The literature on the subject is considerable, but it is scattered over very many journals, bulletins and books, and is not always easy to follow. In it the term "incompatibility" is used extremely loosely and may mean much or little. The author here briefly summarizes the phenomena which occur as the result of slight or pronounced incompatibility in different stock-scion combinations.

The horticulturist is often faced with the problem of growing varieties of fruit in localities where there is no experience to guide him. If he knows that under certain conditions, which may in some respects resemble his own, certain rootstocks have given promising results with particular varieties, at least he has something on which to base his trials. He would be most unfortunate if, as regards the common deciduous tree fruits of commerce, he did not find some guidance in these pages.

The physiologist, moreover, has in this common feature of practical horticultural practice a unique investigational field at his disposal. The author gives him a firm basis on which to work.

First the manifestations or symptoms of incompatibility in fruit trees are considered and their possible causes discussed. Next the compatibility or incompatibility shewn by individual varieties of common deciduous fruit trees in respect of particular rootstocks is noted, considerable attention being paid to the practical field experience of research workers in different parts of the world with particular scions and rootstocks.

Certain general conclusions are drawn with regard to both the symptoms and the cause of inherent incompatibility, and tentative suggestions are made for drawing up a research programme to investigate the problem.

In an appendix covering 40 pages are tabulated the many and often contradictory records of compatibility and incompatibility between particular rootstocks and particular varieties. They should prove helpful not only to the physiological investigator but also to the practical horticulturist.

REPORT OF FOURTH INTERNATIONAL GRASSLAND CONGRESS

The Fourth International Grassland Congress was held in Aberystwyth, Wales, from July 8 to July 23, 1937, under the presidency of Professor R. G. Stapledon.

The report of proceedings has just been issued. It consists of one Volume of 486 pages, which is available from Aberystwyth for two pounds sterling, post free. The report contains a list of the various organizing committees and a complete list of both the participating and non-participating members by country of origin. All the papers presented at the Congress are given in full in either English or German with a short German summary for the English papers and vice-versa.

The proceedings open with an inspiring address from the President wherein stress is given to the great importance of developing our grasslands to the fullest possible extent. The main group of papers are divided into two main sections, plenary and sectional. The former include those of a more general nature and were given before the Congress as a whole. They cover such aspects as grass-drying, pasture types, breeding, the ecotype concept and the value of pastures in erosion control.

The sectional papers fall into six natural divisions as follows:

1. Grassland Ecology, Including Range Management.

This section provides a number of valuable papers on the ecology of pastures in different parts of the world and records progress in methods of renovation under range conditions.

2. Seeds Mixtures:

The influence of legumes in mixtures, the formulation of mixtures for specific purposes and management to control the ultimate outcome of a mixture are dealt with.

3. Plant Breeding, Genetics and Seed Production:

In this section the papers deal with the genetics of red clover, the breeding of grasses, and grassland seed production and pests.

4. Manures and Fertilizers, Soil Aspects of Grassland:

The influence of lime, nitrogen, phosphorus and potash are all dealt with in this division with greatest emphasis on nitrogen. Only one paper is found on soils. The effect of the various fertilizers on sward composition is given consideration.

5. Nutritive Value of Pastures: Fodder Conservation:

Artificial grass drying and grass silage are outstanding in the contributions under this heading. Several papers stress the nutritional aspects of ordinary pastures and forage crops.

6. Pastures, Management, Yields and Economics:

Management problems and results are the most prominent in this section but it includes as well detailed results on the effect of varying treatments on single species and methods of determining botanical composition.

The publication as a whole has been carefully edited and furnishes a valuable treatise on many aspects of grassland. Many of the foremost pasture workers of the world have contributed. It should be found in the library of any one directly interested in the pasture problem.

—L. C. RAYMOND.